CHAPTER 15

SURFACE WATER ENVIRONMENT

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15.1 INTRODUCTION

15.1.1 Introduction

Environmental engineering involving surface waters is a rapidly evolving science. In part, this is due to limited scientific findings and different perceptions as to what constitutes acceptable practice where sensitive surface waters are involved.

Highway construction and operation adjacent to Water of the State, may have limited effects on the water quality. Good engineering design requires the evaluation of non-degrading or less-degrading highway improvements and drainage facilities.

Utah is the second driest State in the Union with only neighboring Nevada receiving less average annual precipitation. To distribute water equitably, a law was passed, in the early days of the state, placing all the water in Utah under the ownership of the state. With the exception of interstate waters, and on a few enclaves such as Military forts and within Indian Reservations, no individual person or corporation "owns" any of the water they make use of in the State of Utah.

Under the Appropriative rights law, the state (State Engineer) distributes water rights to users according to quantity and uses permitted by the law. The right they make use of is tied to a beneficial use only. It is interesting to note that the "Clean Water Act" explicitly acknowledges the preeminence of the Appropriative water law doctrine in the Western States.

The designer may be thrust into a major role in surface water environmental engineering. In general, the designer's role is to determine the hydrology and hydraulic related highway effect and significance on sensitive surface waters. Such determinations shall use surface water assessments and analyses to provide findings on:

- water quality impacts,
- channel stability and mitigation, and
- fishery-compatible drainage facilities.

15.1.2 Purpose

The purpose of this section is to present reliable and accepted engineering practices that should allow the designer evaluate, rank and choose non-degrading or less degrading drainage alternatives. The sound engineering approaches outlined in the following sections, are evidence that highway construction and operation have limited effects on water quality.

Other, more complex practices are briefly noted, to provide a background and suggest possible analytical courses of action. In general, the subjects and practices provided in this chapter should address many of the surface water environmental problems encountered by the designer.

It is imperative that the designer recognizes and impresses on others that all the practices presented or alluded to in this Chapter are not routinely employed on all highway projects nor sites. In reality, rarely would more than one or two practices be needed, and then only on selected projects or at unique sites.

15.1.3 Surface Waters

Present regulations implemented by the Utah Department of Environmental Quality (UDEQ) through the Division of Water Quality owe their "Anti-Degradation" form and logical format in large part to Dr. Grant Borg of the University of Utah. Thanks to his work, by the year 1955, all significant waters and water bodies of the State were grouped according to a hierarchy of beneficial uses and Classes, using clearly identifiable reproducible standards. Now all the waters of the State benefit from some level of protection. Meaningful efforts have been made to restore polluted waters and protect all waters from further degradation.

Classification of Waters reflected distinct beneficial uses. Domestic drinking water (culinary) sources were designated as Class 1 Waters, those protected for in-stream recreational use and aesthetics were designated as Class 2 Waters, those protected for in-stream use by beneficial aquatic wildlife were designated as Class 3 Waters, those protected for agricultural uses were designated as Class 4 Waters, those protected for industrial uses were designated as Class 5 Waters. Please see Appendix 15.A for the current water classification for the waters of the State of Utah.

15.1.4 Sensitive Surface Waters

In general, the primary factors that may make surface waters sensitive are:

- discharge magnitude,
- soil,
- climate,
- chemical,
- biota,
- encroachments, and
- regulations.

Appendix 15.A reference the sensitivity of various waters of the State. Additional information concerning surface waters of the State which are considered to be at special risk can be obtained by accessing the following web site which gives the latest information concerning the total maximum daily loadings (TMDL) for certain pollutant dangers: http://waterquality.utah.gov/watersheds/state.htm

Similarly for proposed UPDES permitted discharges; where the discharge rate will exceed 5 cfs, the following list of alternatives should be considered, evaluated and implemented to the extent feasible:

(a) innovative or alternative treatment options

(b) more effective treatment options or higher treatment levels

(c) alternative discharge locations or alternative receiving waters

(d) improved maintenance of existing treatment systems

(e) other appropriate alternatives

Alternatives would generally be considered feasible where costs are no more than 20% higher than the less costly alternative. At times, less sophisticated treatments that leave the water in the stream, may be more beneficial than more radical methods.

Drainage strategies should maintain the existing level of protection even when this level is higher than required by law.

15.1.5 Functional Values

The functional value of sensitive surface waters are related to such elements as:

- geographic location,
- hydrology,
- climatology,
- geometric setting,
- size,
- quality,
- classification (see Channel Stability and Appendix 15.A), and
- biotic region (see Appendix 15.A).

The interrelationship of these factors for sensitive surface waters determines the water's functional values. These values include such elements as:

- flood control,
- terrestrial wildlife habitat,
- aquatic habitat,
- groundwater recharge,
- aesthetics,
- shore and bank line geometry,
- water temperature,
- scenic and wild rivers designation,
- endangered species habitat, and
- contaminant abatement.

15.1.6 Effect and Importance

Determining a surface water effect without assessing the importance can sometimes be misleading. A solid assessment entails an estimation of the magnitude of the initial and long-term effects. An important aspect is determining if a threshold value has been exceeded and if there is a reversible effect.

15.1.6.1 Effect

This is what occurs to the surface waters as a direct or indirect result of the highway improvement.

15.1.6.2 Importance

Importance shall be determined by analyzing risk (probability or frequency of occurrence) and cost. The analysis should include past or future cumulative effects that can be reasonably expected (often termed the "nibble" effect). Where practicable and useful, a simple comparison shall be made of five conditions:

- hypothesized pristine,
- existing (preconstruction),
- during construction,
- expected post construction, and
- the predicted future.

15.1.7 <u>Threshold Value</u>

This is the value beyond which an adverse effect would probably occur. In surface water environmental engineering, the threshold value concept will be used wherever practicable.

15.1.8 <u>Reversible Effects</u>

It may be necessary to assess whether an effect is reversible or irreversible. Given enough time and resources, surface water effects caused by highway improvements can usually be reversed. Whether the reversal of an effect would be considered as practicable and desirable is the context within which the Department shall address this issue.

15.1.9 <u>Practicable</u>

In negotiations with the resource and regulatory agency(ies), the choices and alternatives may be contingent upon what is practicable. For the purpose of this Chapter, practicable shall mean "available and capable of being done after taking into consideration cost, existing technology and logistics in light of overall project purposes."

This is the definition used in the Memorandum of Agreement (MOA) between the US Environmental Protection Agency (USEPA) and the US Army Corps of Engineers (USACE). See Reference *(15)*.

15.1.9.1 Avoidance

Wherever practicable, avoiding the sensitive surface water is the best and preferred alternative. When avoidance is not practicable, the designer is responsible to show to the resource and regulatory agency(ies) why avoidance is not practicable before any other alternative can be considered.

15.1.9.2 Minimization

Where sensitive surface water disturbances cannot be avoided, such disturbances may be minimized through adjustments in the highway's:

- alignment,
- profile,

- template, and
- other geometry.

The intent is to reduce the impacts to surface water resources when avoidance is not practicable.

15.1.9.3 On-Site Mitigation

Those measures that would allow mitigation to occur at the geographic point of disturbance usually are the most successful. This is because the existing functional values will have the best opportunity to either remain intact or be in a position to quickly regenerate.

15.1.9.4 Off-Site Mitigation

Occasionally, with wetlands and channel modifications, it may not be practicable to provide mitigation at the point of disturbance. This requires that mitigation measures be accomplished away from the disturbed site but usually within the same river basin system, geographic area and biological region; these criteria are identified later in this Chapter.

15.1.9.5 Combination

A combination is the use of two or more of the foregoing alternatives for mitigation at a site.

15.1.9.6 Mitigation Banking

This option would allow banking on mitigated areas and exchanging them for other location where it would be difficult to mitigate.

15.1.9.7 No Mitigation

This alternative is where the responsible regulatory agencies rules without challenge that no mitigation measures are needed to restore a disturbed surface water feature.

15.2 POLICY

15.2.1 <u>Introduction</u>

Set forth in this Section are the policy guidelines of the Department for highway construction that disturbs sensitive surface waters.

15.2.2 <u>Rules and Regulations</u>

All surface water environmental design, construction and maintenance shall be in compliance with the following Federal and State rules, regulations and Memorandums of Agreement (MOAs) and Understanding (MOUs). These are the principal regulation documents applicable to this Chapter; others that may have limited application are listed in the Policy Chapter of this *Manual*.

15.2.2.1 Federal

These are as follows:

- Clean Water Act (33 USC 1251 -1376, DOT Order 5660.1A, FHWA Notices N5000.3 and 5000.4, 23 CFR 650, Subpart B, E, 23 CFR 771, 33 CFR 209, 40 CFR 120);
- National Environmental Policy Act (NEPA);
- Protection of Wetlands (Executive Order 11990, 23 CFR 777); and
- Floodplain Management (Executive Order 11988 (23 CFR 650, Subpart A, 23 CFR 771), amended by Executive Order 12148, DOT Order 5650.2).

15.2.3 Cost Effectiveness

It is hard to assess the cost of some surface water mitigations alternatives at highway encroachments, nevertheless, it is important that any mitigation either be:

- cost effective, or
- provide demonstrably beneficial improvements.

15.2.4 Enhancing Functional Values

In general, it is the intent of the Department to provide only those mitigation measures necessary to maintain the existing functional values or acceptable equivalents of those sensitive surface waters disturbed by a highway action. Only where a cost-effective benefit to the Department can be demonstrated shall an existing function's values be enhanced, unless otherwise mandated by the responsible resource and regulatory agency(ies) as a permit requirement.

Examples of some negotiable benefits are:

- wetland banking;
- acceptable substitution of a different, cost-effective, easier to construct and/or maintain functional value; and

15.2.5 Evaluation Complexity

The detail of any environmental evaluation involving an assessment or analysis should be commensurate with the:

- surface water sensitivity,
- importance of the resource's functional values, or
- resource and regulatory agency(ies) mandates.

Close coordination and ongoing negotiation with the resource and regulatory agency(ies) should be maintained throughout the plan development process by the UDOT Environmental Staff to ensure an acceptable level of assessment or analysis detail. Only that detail essential to securing approval of the highway project from the responsible resource and regulatory agency(ies) shall be developed. In general, surface water assessments will suffice for most sites involving sensitive surface waters. Where such activities as a major alteration of a surface water feature is required, or when a detailed analysis is mandated by the responsible resource and regulatory agency(ies), a surface water analysis shall be prepared.

15.2.6 Surface Water Assessment

An assessment is a judgmental or subjective form of surface water analysis and forgoes the need for a complex, objective type of study and/or a study requiring large amounts of costly data.

Appendix 15.A includes the Beneficial Use Classification of Waters of the Sate from the Utah Division of Water Quality. The classification shall be used to assess the effect of the proposed project on these waters. Surface water concerns raised by the responsible resource and regulatory agency(ies) should be resolved with the Department's standard Best Management Practices (BMPs).

15.2.7 Surface Water Analysis

An analysis is more quantitative than an assessment. The issues to be addressed in a surface water analysis should be limited to only those that the UDOT Environmental Staff determine to be relevant based on their negotiations with the responsible resource and regulatory agency(ies). All other issues should continue to be addressed at the assessment level of investigation. Analyses should as a minimum, address the pertinent attributes of Appendix 15.A.

15.2.8 Combined Evaluation

Commonly, a particular site would not require an assessment or analysis of all the attributes reflected in Appendix 15.A. As such, some attributes at a particular site may only require an assessment level of investigation whereas other sites may require an analysis level of investigation, and some sites might be ignored altogether. Where this occurs, a combined assessment and analysis for a highway action should be used.

15.2.9 Permit Criteria

The disturbance of sensitive surface waters requires a permit. The conditions of such permits may mandate hydraulic design criteria that should be included in the design. These criteria should be identified early in the design process to minimize delays in developing the contract plans. For this reason, the designer shall maintain close contact with the proper regulatory agency(ies) responsible for a surface water permit. These permits and/or certifications include:

- USACE Section 404 permits,
- State Section 401 Certifications,
- USCG Permits.

Following is a brief description of the permit and requiring agency:

Water Resource Permit Summary

404 Permits

Purpose – Authorizes the permittee to perform excavation (dredging) or place various fill materials into "jurisdictional" wetlands. Because special aquatic sites are included in the general definition this permit is also needed when altering river, stream or creek channels. The permit may be a Nationwide or an Individual permit. Each will outline mitigation and monitoring requirements and other special conditions that must be followed. This permit must be obtained prior to advertising the project for construction.

Agency with Jurisdiction - **US Army Corps of Engineers**
Utah Regulatory Unit
533 West 2600 South
Bountiful, UT 84010
295-8380

Stream Alteration Permits
Purpose - Authorizes the permittee to modify or alter a natural stream channel.Necessary in order to modify or alter a natural stream channel. A natural stream channel is defined as a natural drainage feature with a defined bed and bank independent of flow.

Modification or alteration activities may include bridge crossings, bank stabilization, scour mitigation, spur dike installation, etc. The permit will outline special conditions that must be followed during construction. This permit must be obtained prior to advertising the project for construction.

Agency with Jurisdiction: **Department of Natural Resources**
Water Rights Division
1594 West North Temple, Suite 200
Box 146300
Salt Lake City, Ut 84114-6300
(801) 538-7377

Utah Pollutant Discharge Elimination System (UPDES) Permits
Purpose - Authorizes the permittee to modify or alter a natural stream channel. Necessary for all projects that will disturb more that 1 acre of surface area. This general permit allows the permittee to temporarily discharge storm water from a specified disturbed construction site. This permit must be obtained prior to construction activities. The process for obtaining this permit consists of preparation and submittal of a Notice of Intent form to the State Division of Water Quality (DWQ). At the completion of the project the permit is terminated by preparing and submitting a Notice of Termination form to the same agency.

Agency with Jurisdiction: **Department of Environmental Quality**
Division of Water Quality
288 North 1460 West
Salt Lake City, UT 84116
fax (801) 538-6016

Construction Permit (for Permanent Detention Pond Features)
Purpose - Authorizes the permittee to construct permanent detention pond features that discharge into waters of the state/US. The design of the pond is reviewed for adequate

capacity, settling time, controlled outlet discharge. This permit is obtained by UDOT Region hydraulics or design staff prior to advertising the project for construction.

Agency with Jurisdiction: **Department of Environmental Quality**
Division of Water Quality
288 North 1460 West
Salt Lake City, UT 84116
fax (801) 538-6016

Flood Plain Encroachment Permit

Purpose - For all proposed construction activities, or alterations to existing structures within the base flood plain (100 year event). Alteration is defined as any man-made change to improved or unimproved real estate, including but not limited to buildings or other structures, mining, dredging, filling, grading, paving, excavation or drilling operations. This permit is obtained from the local community permit official. Coordination with FEMA is also required.

The permit official will review the project plans to determine if the proposed project will cause a rise in base flood elevations. This permit must be obtained prior to advertising the project for construction.

Agencies with Jurisdiction: **Federal Emergency Management Agency**
Comprehensive Emergency Management
1110 State Office Building
Salt Lake City, UT 84114
(801) 538-3750

15.3 DESIGN CRITERIA

15.3.1 General Criteria

General criteria to be considered at all surface water locations include the following:

- mitigation alternatives, and
- Best Management Practices.

15.3.1.1 Mitigation Alternatives

The following six mitigation alternatives, listed in order of priority, should be routinely considered at environmentally sensitive locations as determined by the Department, when identified by a resource agency or when mandated by the regulatory agency(ies):

- avoiding the impact altogether;
- minimizing the impact by limiting its degree, magnitude and implementation;
- rectifying the impact by repair, rehabilitating and/or restoration;
- reducing/eliminating the impact through preservation and/or maintenance;

- compensating for the impact with substitute resources; and/or
- no mitigation when approved by the responsible regulatory agency(ies).

15.3.1.2 Best Management Practices

Best Management Practices (BMPs) should be routinely used to mitigate expected adverse surface water impacts.

15.3.2 Functional Values

- The seasonal set of functional values which exist under normal conditions at the proposed construction site, should be used as a base line to evaluate the expected fate of the functional values during four periods:

- preconstruction,
- during construction,
- immediate post construction, and
- long-term (future).

15.3.3 Design Criteria

Below are design criteria for the following six hydraulic-related surface water features:

- water quality,
- channels,
- lakes or ponds,
- wetlands,
- fish passage, and
- stream geometry and cover.

15.3.3.1 Water Quality

At a minimum, three design criteria are considered when selecting the base-line water quality for a project:

- seasonal preconstruction quality,
- beneficial use Classification given to the Waters in Table 1
- requirements of the responsible resource and regulatory agencies.

There are two design criteria for surface water quality:

- Short Term. Water quality occurring during and immediately following construction may be temporarily degraded within the limits approved by the responsible regulatory agency(ies).

- Long Term. Water quality shall, at a minimum, equal the seasonal preconstruction quality as determined by the Department or as mandated by the responsible regulatory agency(ies).

Water quality shall be monitored when it is:

- in the best public interest or for safety reasons,
- monitoring requested by a resource agency as agreed to by the Department,
- mandated by the responsible regulatory agency(ies), or
- jointly approved Monitoring Plans by the Department and the responsible regulatory agency(ies).

15.3.3.2 Channels

The following criteria are useful when documenting the existing and future functional values exhibited by channels:

- Classification,
- Ordinary High Water (OHW),
- stability, and
- mitigation.

15.3.3.2.1 Classification

Channels should be classified as to type and stability using the methodology detailed in HEC 20 "Stream Stability at Highway Structures". Classifications should be determined for the existing (preconstruction) and expected long-term (future) time periods.

15.3.3.2.2 Ordinary High Water

If a suitable gage record exists the Ordinary High Water (OHW) line is best determined using a Log Pearson Type III analysis as described in HEC 19 "Hydrology" to estimate the mean annual flood ($Q_{2.33}$). The OHW line can then be determined from a stage discharge relationship calibrated to the stream reach being investigated. When gage data is lacking then the OHW line can be determined based on any of the following design criteria (adjusting for the current hydrologic regime):

- a distinct boundary line delineated by the lack of "upland vegetation" indicating the location of the cyclically saturated and thus inhospitable channel soils,
- a sometimes slight, sometimes pronounced shelving or natural line impressed on the bank or shore,
- changes in soil character brought about by the habitual saturation induced by OHW,
- the presence of litter and debris left by OHV events, and
- a characteristic inundation or benching line of the Normal Operating Pool Elevation (NOPE) for reservoirs.

15.3.3.2.3 Stability

Channels should be classified as to type and stability using the methodology detailed in HEC 20 "Stream Stability at Highway Structures". Classifications should be determined for the existing (preconstruction) and expected long-term (future) time periods. A channel exhibiting evidence of braiding and headcutting will be considered unstable for the existing flow regimes.

The Department should take no action that would further destabilize a channel.

15.3.3.2.4 Mitigation

There are four criteria to consider before electing to mitigate an unstable channel with channel control facilities:

- cost effectiveness,
- necessary to protect the highway,
- necessary to protect adjacent property,
- requested by the responsible resource and regulatory agencies.

Other channel criteria for stabilizing a channel shall apply as set forth in Chapter 8 "Channels" of this *Manual*.

15.3.3.3 Lakes or Ponds

Criteria for lakes or ponds shall be established on a case basis.

15.3.3.4 Wetlands

Jurisdictional wetlands, including special aquatic sites, will continue to be classified and delineated using the Corps of Engineers Wetlands Delineation Manual (Technical Report Y-87-1 January 1987). Other non-jurisdictional wetlands can be conveniently classified as shown in Appendix 15.A. A widely accepted engineering classification relating to hydrology and hydraulics is not currently available.

More details on wetlands delineation, classification, hydrology, creation and restoration can be found in Appendix 7.E, Chapter 7 "Hydrology" of this *Manual*, Appendix 15.D of this Chapter and Chapter 10 of Reference *(1)*.

15.3.3.5 Fish Passage

There are two design criteria to consider for determining when the Department will provide or enhance fish passage through a drainage facility:

- Waters in the Class 3 designation (Appendix 15.A)
- Requested and justified by the responsible resource and regulatory agency(ies).

Fish passage design criteria are addressed in six parts:

- general,
- channels,
- bridges,
- culverts, and
- debris barriers.

15.3.3.5.1 General

The following design criteria sets expectations for fish-passage design for both new structures and replacements. Priority setting and design details should be accomplished as part of an interdisciplinary process with the responsible resource agency. Fish passage location and design should, in order of importance:

- Minimize the consequences of plugging and causing the overtopping of the roadway and/or an upstream flooding hazard, including the ability to prevent diversions
- Provide adequate hydraulic capacity, including the requirement that under normal conditions the headwater depth be less than, or equal to the height of the structure,
- avoid adverse interference with any flood control or irrigation facilities,
- be practicable and cost effective, and
- exhibit reasonable ease of maintenance

General fish passage design criteria to consider that are applicable to all drainage facilities are:

- During flood periods, avoid causing velocities in and adjacent to the drainage facility that exceed the lower range of natural, main channel velocities.

- During flood periods, avoid causing unnaturally high velocities for a reasonable period of time at some point during the runoff hydrograph associated with an expected spawning run.

- During low flows, avoid shallow flow depths through and adjacent to a drainage facility.

Locations and designs involving culvert lengths, straight channel reaches required under bridges and channel reaches shall be sensitive to the following general criteria. These criteria are a function of the preferred distance between resting areas:

15.3.3.5.2 Channels

Channel analyses and the design for channel relocations that are environmentally sensitive shall be in accord with the design criteria in Chapter 8, “Channels” of this *Manual*.

15.3.3.5.3 Bridges

There are two environmentally related bridge location and design criteria to be considered where practicable:

- Structure opening width should provide a sufficient span so as to avoid constricting the stream or accelerating velocity at the 2-year high flow. (Active channel width or bed width or bank to bank width at OHW are also used in describing this dimension.)
- provide a low flow channel compatible with the channel’s natural flow regime.

15.3.3.5.4 Culverts

Environmentally related culvert location and design criteria:

- Provide a sufficient span or structure opening width so as to avoid overly constricting the stream or accelerating velocity at the 2-year high flow. [Active channel width or bed width or bank to bank width at OHW are also used in describing this dimension.]

- When using conventional closed conduit culverts place the culvert invert below the streambed elevation so that the natural stream gradient and substrate material can be re-established through the structure.

- While the use of open bottom culverts is encouraged before selecting open bottom arches in lieu of conventional closed round or arched pipe conduits [which by their nature eliminate foundation scour risks] evaluate the additional environmental impacts to channel banks and riparian values which the installation of scour resistant foundations for such bottomless structures can often create.

- Baffles, weirs, and similar artificial devices inside the culvert should only be employed when the use of natural stream materials is impractical. Baffles and weirs should only be used by experienced designers.

- Either avoid high outlet velocities resulting in a scour hole that precludes fish entry, or provide a permanent downstream pool that inundates the lower portion of the culvert to where fish may enter the culvert during periods where passage is required.

- Evaluate draw-down and turbulence at the culvert inlet as well as barrel and outlet velocities by comparing them with similar naturally occurring and existing velocity distributions in representative adjacent upstream and downstream reaches.

- Consider placement of one or more larger riprap elements [fish boulders or derrick rock] to provide a resting area on the channel periphery immediately upstream from the culvert entrance that is readily accessible to emerging fish.

15.3.3.5.5 Debris Barriers

Deploy any essential debris barriers in a manner that minimizes the potential for becoming a barrier to fish passage during periods where passage is required.

15.3.3.6 Stream Geometry and Cover

Channel disturbances may require design criteria for the following:

- riparian cover,
- in-stream cover,
- riffles,
- pools,
- substrate,
- bank geometry, and
- conveyance.

15.3.3.6.1 Riparian Cover

Riparian vegetation that is disturbed by construction should be replaced in kind or as directed by the UDOT Landscape Architect. In-stream cover, riffles and pools should be provided using measures similar to those shown in Appendix 15.B.

15.3.3.6.2 Substrate

As practicable, the natural, preconstruction substrate should be replicated in all disturbed areas except where it is necessary to provide some type of erosion protection or armor for stability.

15.3.3.6.3 Bank Geometry

In rural areas, banks should be left in their natural form except where it is necessary to provide for such functions as ingress and egress of such items as the following:

- vehicles,
- boats,
- livestock,
- swimmers,
- amphibians, and
- water fowl.

In certain urban areas, aesthetics and safety may dictate the need for uniform channel alignments and sloped banks.

Whenever practicable, bank protection design should allow for and incorporate soil materials which will encourage the natural recovery of appropriate vegetation. This may involve flatter slopes to insure stability as well as initial pole plantings or other direct transplanting of native vegetation.

15.3.3.6.4 Conveyance

As practicable, the design should replicate the conveyance associated with the natural stage-discharge relationship for the low-flow channel (dominate flow channel) and the attendant overbank floodway. These two replications shall be considered separately.

15.4 DESIGN CONSIDERATIONS

15.4.1 Introduction

Surface water environmental design considerations include:

- water quality,
- channels,
- lakes and ponds,
- wetlands,
- fish passage,
- stream geometry, and
- riparian cover.

The following information is general guidelines that the designer could use in design where it is demonstrably appropriate. For most highway projects, the surface water environmental design considerations are as agreed to by UDOT personnel through negotiations with the responsible resource and regulatory agencies.

15.4.2 Water Quality

For most highway projects water quality is considered as the interrelated combination of:

- soil erosion,

- pollutant loading,
- aesthetic appearance,

Note: Only the first two factors will be addressed in this Chapter.

15.4.2.1 Soil Erosion

A baseline surface water assessment or surface water analysis documenting existing conditions may be useful where there is a demonstrable concern that highway induced soil erosion is or will cause an adverse effect on **Category 1 - High Quality Waters -** [listed in R317-2-12.1]. The Region's Environmental Engineer should set the scope of any such special assessment in collaboration with his or her counterparts in the responsible resource and regulatory agencies.

The study should be structured to detect pollutants and to identify whether an erosion based pollutant loading source is caused by the Department or by others. Chapter 16, "Erosion and Sediment Control" should help quantify sediment transported to receiving surface waters.

15.4.2.2 Pollutant Loading

Pollutants, other than sediment, may originate from:

- highway construction sites,
- in-situ hazardous material exposed by construction,
- highway maintenance activities,
- adjacent land use, and
- highway surfaces and storm drains.

15.4.2.2.1 <u>Highway Construction Sites</u>

Normally, BMPs will control pollutants that might originate at highway construction sites.

15.4.2.3 Management Measures

15.4.2.3.1 <u>General</u>

Pollutants detected in highway runoff such as solids, heavy metals and organics (found in fuel and motor fuels) correlate directly with traffic volume. Most of these solids and heavy metals also exist naturally in Utah soils, they are the source of the background levels commonly detected pollutants in surface waters. In support of the anti-degradation water policies of the State a chief concern then is to prevent pollutant loadings in highway runoff from further degrading the existing quality of the receiving water body.

Highway runoff pollution may affect the water quality of any receiving waters through:

- shock and immediate (acute) loadings, and
- chronic effects due to prolonged accumulation.

Management techniques must recognize these effects and the characteristics of the commonly encountered pollutants and identify appropriate mitigation strategies for them.

Extensive research conducted by the FHWA *(14)*, identified an Average Annual Daily Traffic (AADT) threshold of 30 000 vehicles/day. Their report concluded that if traffic is below this threshold, there will be few relevant effects. Any potential effects will be commonly short-term, localized shock loadings from temporary water quality degradation; and chronic effects are essentially nonexistent.

Other pollutants such as herbicides and nutrients are not a function of AADT because they commonly derive from such factors as highway maintenance activities and adjacent land use contributions. Management techniques for traffic induced as opposed to maintenance-related pollutants are different.

The ability of a pollutant to migrate to receiving waters from the right-of-way is a function of its:

- chemical nature;
- physical-chemical properties (e.g., water solubility, vapor pressure);
- tendency to adsorb to organic matter or sediment; and
- interception by any mitigation or control measures.

Of the major migration processes, the key mechanism for transporting a pollutant originating on a highway right-of-way is a combination of adsorption and settling. This is due to many of the runoff constituents being in a settled, particulate form. This is further enhanced because soluble, organic chemicals and heavy metals tend to adsorb (see Table 15-1) to suspended sediments, which in turn will settle given sufficient time and a suitable environment. Once settled, these pollutants will be most commonly transformed through the biological action of:

TABLE 15-1 — Fate of Pollutants By Management Measures

Pollutant	Management Measures			
	Vegetative Controls	Detention Basin	Infiltration Systems	Wetlands
Heavy metals	Filtering	Adsorption Settling	Adsorption Filtration	Adsorption Settling
Toxic organics	Adsorption	Adsorption Settling Biodegradation Volatilization	Adsorption Biodegradation	Adsorption Settling Biodegradation Volatilization
Nutrients Solids	Bioassimilation Filtering	Bioassimilation Settling	Adsorption	Bioassimilation Adsorption Settling
Oil and Grease	Adsorption	Adsorption Settling	Adsorption	Adsorption Settling
BOD	Biodegradation	Biodegradation	Biodegradation	Biodegradation
Pathogens	Not applicable	Settling	Filtration	Not applicable

Source*:* Reference *(9)*.

- degradation,
- assimilation by microbial, and

- assimilation by rooted vegetation.

Design of optimal settling management measures are complicated by the fact that suspended loadings in highway runoff is generally associated with very fine materials having low settling velocities. Mitigation strategies and practices should be designed as practicable to take advantage of the following highway practices and runoff characteristics:

- Discharges from frequent minor storms are more critical than discharges during infrequent major storms.

- First-flush conditions result in relatively high pollutant concentrations that can induce shock-loading and a short-term degradation of the water quality of receiving waters.

- Conventional UDOT Best Management Practices (BMPs) will commonly suffice for most highway activities.

- Loadings of heavy metals and other toxic materials tend to be of greater concern than loadings of nutrients that have a high biological oxygen demand (BOD).

- Critical pollutants such as heavy metals tend to appear primarily in suspended form.

- Measures designed for storms producing less than 1 in of rainfall will control nonpoint pollution discharges for approximately 90% of the storms each year.

- Runoff from large, uncontrolled storm events tends to produce flows from non-urban areas that can dilute discharges from the paved, urban areas.

Commonly, pollution management relies on controls for minor storms having a recurrence interval of one year or less. As such, management techniques that isolate first-flush discharges can take advantage of the smaller required storage capacities for these discharges. The larger storage capacities required when these facilities are perceived as being needed to treat all runoff flows need not be considered unless mandated by the responsible resource and regulatory agency(ies).

First-flush effects are attributed primarily to the “washoff” of particles from paved areas. This means that, compared to more rural areas, the first-flush effects from urban areas tend to exhibit:

- relatively high loadings of suspended sediments,
- a higher per-acre concentration of heavy metals (contributions from vehicular traffic), and
- less nutrient loadings than unpaved areas.

15.4.2.3.2 Effectiveness of Management Measures

At this time, only qualitative ratings of management techniques can be offered. This is due to the variance in the design and management of these measures and the intangible site-specific factors that determine the runoff characteristics and pollutant loads. These subjective ratings are shown in Table 15-2.

Notably, the measures in Table 15-2 may require additional right-of-way for construction and maintenance. Because mitigation is often a function of a high AADT which, in turn, commonly occurs near urban areas, any additional right-of-way may be very costly. As such, cooperative stormwater management agreements with local governments to share the benefits and cost are encouraged. The applicability and cost of pollution management measures are functions of the highway configuration. Four common highway configurations and the applicability of various pollution management measures are shown in Table 15-3.

Measures listed in Table 15-2 which require routine maintenance to be considered effective include:

- *Street Cleaning* — Neither sweeping nor street flushing are reliably effective unless routinely performed.
- *Conventional Catch Basins* — Unless cleaning is routinely performed catch basins may be a cause of pollution rather than a management measure.
- *Dry Detention Basins* — Although the Department considers these as effective for management of peak flows, a detention time of a few hours is insufficient to permit settling of the smaller fractions of the suspended materials associated with some pollutants. See “Extended Dry Detention Basin” below.

TABLE 15-2 — Effectiveness and Applicability of Management Measures

Management Measure	Pollutant Removal Effectiveness				
	Type	Particulates	Heavy Metals	Pesticides	Organics
Curb elimination	Post deposition	H	H	N/A	H
Litter control	Source	L to H	L to H	L to H	L to H
Grassed channels	Post runoff	H	H	H	H
Overland flow	Post runoff	H	H	M	H
Dry detention basins	Post runoff	L to H	L to H	M	H
Wet retention basins	Post runoff	H	H	L to M	L to M
Infiltration systems	Post runoff	H	H	H	H
Wetlands (Wet)	Post runoff	H	H	H	H
Street cleaning	Post deposition	L to H	L to H	M to H	M to H
Conv. Catch basins	Post runoff	L to M	L to M	L	L
Filtration	Post runoff	L to M	L	N/A	H

Management Measure	Other Considerations				
	Type	Relative Capital Costs per Acre*	Additional Land Requirements	O & M Costs Routine	Nonroutine
Curb elimination	Post deposition	L	M to H	O	O
Litter control	Source	L	O	O	O
Controlled use of:					
deicing chemicals	Source	L	O	O	O
pesticides/herbicides	Source	L	O	O	O
Grassed channels	Post runoff	L	L	L	L
Overland flow	Post runoff	L	M to HL	L	L
Dry detention basins	Post runoff	M	M	L	L
Wet retention basins	Post runoff	H	H	L	L
Infiltration systems	Post runoff	H	M	H	H
Wetlands	Post runoff	M to H	M to H	L	L
Street cleaning	Post deposition	L	O	H	O
Conv. Catch basins	Post runoff	M to H	L to M	H	H
Filtration	Post runoff	L to M	O	M	M

Ratings: H = high, M = medium, L = low, O = none, N/A = not applicable

**Based on additional capital costs required for nonpoint pollution management per acre.*

Source: Reference *(9)*.

TABLE 15-3 — Applicability of Pollution Management Measures vs. Highway Configuration

Management Measure	Planned Highway Construction			
	Interchange	Elevated Highway	At-grade Highway	Depressed Highway
Vegetative filters				
Grassed channel*	High	Low	High	Low
Overland flow**	Medium	Low	High	Low
Detention/retention basins	High	Medium	Medium	N/A
Infiltration systems				
Basin	High	Medium	Low	N/A
Trench	Low	Medium	Medium	N/A
Well	Medium	Low	Low	N/A
Wetlands	Medium	Low	Low	N/A
Management Measure	**Existing Highway Retrofit**			
	Interchange	**Elevated Highway**	**At-grade Highway**	**Depressed Highway**
Vegetative filters				
Grassed channel*	Medium	Low	High	Low
Overland flow**	High	Low	High	Low
Detention/retention basins	Medium-High	Medium	Medium	N/A
Infiltration systems				
Basin	Medium-High	Medium	Medium	N/A
Trench	Medium	Low	Low	N/A
Wetlands	Low-Medium	Medium	Medium	N/A

*where grass will grow without irrigation **over vegetated NOT bare ground

Source: Reference *(9)*.

Effective management measures, in order of priority, are discussed below. This prioritization is based on:

- relative effectiveness,
- adaptability to highway design,
- right-of-way requirements,
- ease of operation, and
- maintenance requirements.

BEST MANAGEMENT PRACTICES. These are measures commonly used by the Department. In the arid and semi-arid regions do not use vegetative filters; use Standard BMP’s These measures are discussed in detail in Appendix 15.B.

VEGETATIVE FILTERS. In the wetter areas of the State, which can support vegetation having the necessary density, vegetative filters are the Department’s preferred control measure because they are:

- effective for highway runoff pollution,
- adaptable to a variety of site conditions,

- flexible in design and layout,
- the lower cost alternative, and
- able to be easily used alone or as a combined measure.

Vegetative measures include the following:

- grassed channels, waterways, ditches or swales of sufficient length and design to inhibit erosion and enhance the settling of suspended solids; and

- overland flow through a filter strip where such strips consist of grass or forested vegetation of sufficient width and design to filter pollutants from sheet flow runoff and increased filtration.

Where they can be successfully propagated vegetative filters provide an acceptable pollution management measure for runoff being conveyed from point to point. Such controls also serve as the runoff collection and conveyance system, both as a single management measure and as a link between other measures. These combinations are particularly desirable where the designed length and/or width of a grassed channel is unobtainable.

EXTENDED DRY DETENTION BASIN/WET RETENTION BASIN. The purpose of these types of basins is to increase the runoff residence time so as to allow a greater portion of the finer pollutant bearing materials to settle and be trapped in the basin.

General guidelines for these types of basins follows:

- design extended detention capacity for the typical annual (2- year) runoff event,

- size the discharge orifice so as to provide a hydrograph delay time of approximately 24 h for this annual event, and

- size peak discharge controls to safely pass the higher flow less frequent runoff events through the basin with peak discharge controls sufficient to control flooding.

WET RETENTION BASIN. Wet retention basins are designed so that the contributing drainage area and/or groundwater is capable of supporting a permanent pool. Such a pond provides enhanced pollutant removal through both settling of particulates as well as the biological uptake of soluble contaminants.

Because they have the ability to assimilate large quantities of suspended and dissolved materials from inflow wetlands can be used to mitigate pollution from highway runoff. In a sense wetlands can be considered as a subset of wet retention ponds. The primary differences to be considered in the design are that wetlands:

- remove pollutants primarily through sedimentation and vegetative uptake,
- use vegetation as pollutant removal mechanism,
- require low flow-through velocities, and
- respond best to a diffuse or “sheet flow” flow regime.

Ideally wetlands should receive inflow from vegetated conveyance facilities or a wet detention pond. It must be recognized that conditions favorable to wetlands (high watertable, impervious clay soils) contribute to the premature destruction of pavement structures.

INFILTRATION SYSTEM. Because of their high maintenance costs and their potentially destructive effects on the highway subgrade and pavement structure infiltration systems should only be used if other methods are shown to be impractical. Their ability to reduce pollutant loads in runoff may, under some circumstances, make them an acceptable management measure.

Whether used alone or in combination with other measures, an infiltration system(s) is effective only if:

- soils or subsoils are moderate to highly permeable,
- groundwater table is below the lowest infiltration point,
- runoff inflow is relatively free of suspended solids,
- storage is sufficient to contain the design runoff during the required infiltration period

In addition, the infiltration facility storage volume should be sufficient to contain the design runoff if either of the following design values are used. Design the infiltration facility to exfiltrate either:

- "first-flush" (0.4-in runoff per impervious acre),
- 1-in runoff per impervious acre, or
- all runoff up to a 2-year event.

Their effectiveness is shown in Table 15-3.

COMBINED SYSTEMS. When practicable and effective, management costs can be reduced through the use of combinations of measures. Combinations of measures may:

- increase pollutant removal effectiveness,
- allow for filtration of suspended solids, and
- overcome any site-limiting factors.

Examples of combination systems include:

- use of overland flow through vegetative filters (strips and channels) and/or wetlands to filter suspended sediments from upstream runoff before it reaches an infiltration basin or trench.

WATER QUALITY INLET. These inlets are designed to trap and remove sediment and hydrocarbon loadings before they enter a storm drain to prevent their commingling and mixing with other relatively clean storm drainage. These facilities have a high initial cost and must be frequently cleaned. To be cost effective, the use of these inlets are limited to areas where high concentrations of oils from small contributing areas are expected (e.g., maintenance shops, gas stations, certain industrial areas). General guidance includes the following (see also Reference *(12)*):

- Use a three-chambered structure.

- Chamber One traps particulates and has two, 6-in orifices (with trash rack) at mid-water depth through a partition between Chambers One and Two.

- Chamber Two traps floating oil and has an inverted elbow pipe to regulate water levels in both Chambers One and Two.

- Chamber Three receives discharge from Chamber Two and has an overflow, outfall pipe set with the crown below the horizontal invert of the inverted elbow pipe from Chamber Two.

- An access manhole is provided into each chamber.

- These inlets are not considered for attenuating peak discharge rates in a storm drain.

- Inlets must be cleaned at least twice each year.

MISCELLANEOUS MEASURES. Seven relatively effective, low-cost management measures applicable to many sites are suggested at this time:

- *Curb Elimination* — Omitting curbs encourages the transport of pollutants off the roadway and/or the migration of pollutants into vegetated roadside areas. *Litter Control* — Litter control programs will, as a secondary purpose, achieve pollutant reduction benefits through the elimination of pollution sources.

- *Pesticide/Herbicide Management* — Such factors as limited application, strict controls, employee training and close supervision will minimize pollution.

- *Reduction of Direct Discharges* — Avoid the direct discharge of highway runoff into receiving waters or ground waters by using effective management measure(s).

- *Reduction of Runoff Velocity* — Encourage bed-load deposition by lowering velocities through gradient reduction using drop structures and/or baffles and by providing heavily vegetated waterways.

- *Establish and Maintain Vegetation* — Where adequate excess conveyance capacity exists maintenance of dense, vegetal cover and limited mowing provides pollutant reduction through filtration, sediment deposition, infiltration and, in some cases, biological assimilation of pollutants by the vegetation.

Management measures for more specific sites are contained in Appendix 15.B of this Chapter.

15.4.3 Channels

Chapter 8 "Channels" addresses the hydraulic design of channels. Desirable environmental functions and values of channels depend on a number of factors, including:

- terrestrial habitat,
- aquatic habitat,
- riparian habitat,
- flood conveyance,
- flood storage,
- recreational uses,
- agricultural uses, and
- municipal uses.

Channel stability mitigation measures, where cost effective, can be employed as set forth in Chapter 8, "Channels" and Chapter 17, "Bank Protection."

15.4.4 Lakes or Ponds

The sensitivity of the various lakes and ponds in the State can be determined from Appendix 15.A. Additional information concerning ponds or lakes of the State which are considered to be at special risk can be obtained by accessing the following web site which gives the latest information concerning the total maximum daily loadings (TMDL) for certain pollutant dangers: http://waterquality.utah.gov/watersheds/state.htm

Designs are to be established on a case by case basis in collaboration with the responsible resource and regulatory agencies.

15.4.5 Wetlands

Federal laws, Executive Orders and FHWA rules and regulations mandate that there be no net loss of wetlands.

15.4.5.1 Wetland Assessment

Assessments of existing wetland functional values will be made in cooperation with USACOE using the USACOE 1987 Manual. Quantitative wetland functional values can be estimated using the guidelines as shown in Appendix 15.D. The Environmental Staff is responsible for functional value estimates in cooperation with USACOE.

15.4.5.2 Wetland Mitigation

Mitigation measures are those actions that reduce or eliminate the adverse effects of a proposed action to acceptable levels. At the same time, they may compensate for the affected area for project-related losses. Five ways to mitigate losses are listed below in order of priority for regulatory purposes:

- Avoid the effect altogether by not taking a certain action or part of an action.
- Minimize the effect by limiting the degree or magnitude of the action or its implementation.
- Compensate for the effect by repairing, rehabilitating or restoring the affected environment.
- Reduce or eliminate the effect over time by preservation and maintenance operations during the life of the action.
- Compensate for the effect by replacing or providing substitute resources or environments.

The 1990 Memorandum of Agreement (MOA) between USACE and USEPA *(15)* and Reference *(10)* provides guidance regarding mitigation alternatives. When it is determined that the mitigation measures will include either restoration of existing damaged wetlands or the creation of new wetlands, the procedures outlined in Appendix 15.D provide additional guidance.

15.4.5.3 Wetland Banking

Wetland banking is a variant of compensatory mitigation and requires agreement between the Department and the USACOE. There are generally five essential considerations in a wetlands banking program:

- The Department establishes new wetlands for the purpose of “banking” them for future mitigation use or purchases such wetlands within a wetland bank created by others.
- These new wetlands are considered “bank credits” available for use on future highway projects.
- Bank credits are used to mitigate wetlands disturbances on future highway projects.
- Credit value is generally finalized at the time it is used.
- Compensation wetlands bank credits, when used, are generally in the same geographic or hydrologic region of the wetlands to be disturbed by a future project.

The designer is cautioned that any wetland construction or enhancement for wetland banking purposes must be carefully considered in light of future reconstruction of a proposed project. Proposed wetland bank construction or enhancement must not be such as to curtail or complicate future highway improvements and/or maintenance.

15.4.6 Fish Passage Criteria

Culverts

Fish passage is historically the primary concern with the Department’s culvert type drainage facilities in **Class 3 Waters of the State**. Failure to consider fish passage may block or impede upstream fish movements in a number of ways:

- The outlet of the culvert is installed above the streambed elevation impeding or blocking the free movement of fish through the culvert or:
- The formation of a scour hole at the culvert outlet lowers the streambed downstream of the culvert outfall and the resulting dropoff or perched pipe creates a similar vertical barrier.
- An excessively high outlet velocity may also create an impediment to normal fish passage.
- Excessively high velocities occurring within the culvert barrel can create an impediment to fish transiting the culvert.
- Excessive drawdown, turbulence or accelerating flow at the culvert inlet may prevent fish from exiting the culvert.
- In very long culverts the loss of quiescent water locations found in a natural channel in which fish can rest can create an impediment to fish transiting the culvert.
- In rare instances debris barriers (including ice) upstream or within the culvert may limit fish movement. Note that such an installation is undesirable from a safety point of view as it can easily induce flooding and damage to the highway itself.
- Excessively shallow flow depths within the culvert during minimum flow periods may impede or prevent fish passage.

Generally, maintaining subcritical flow throughout the culvert facility will result in successful fish passage.

When designing for fish passage consider, at a minimum, the following attributes:

- Provide a sufficient span or structure opening width so as to avoid overly constricting the stream or accelerating velocity at the 2-year high flow. [Active channel width or bed width or bank to bank width at OHW are also used in describing this dimension.]

- When using conventional closed conduit culverts place the culvert invert below the streambed elevation so that the natural stream gradient and substrate material can be re-established through the structure.

- When using open bottom evaluate the larger construction "footprint" and generally significantly greater environmental impacts to channel banks and riparian values which the installation of scour resistant foundations for such bottomless structures can often create.

- Baffles, weirs, and similar artificial devices inside the culvert should only be employed when the use of natural stream materials is impractical. Baffles and weirs should only be used by experienced designers.

- Either avoid high outlet velocities resulting in a scour hole that precludes fish entry, or provide a permanent downstream pool that inundates the lower portion of the culvert where fish may enter the culvert during periods where passage is required.

- Evaluate draw-down and turbulence at the culvert inlet as well as barrel and outlet velocities by comparing them with similar naturally occurring and existing velocity distributions in representative adjacent upstream and downstream reaches.

- Consider placement of one or more larger riprap elements [fish boulders or derrick rock] to provide a resting area on the channel periphery immediately upstream from the culvert entrance that is readily accessible to emerging fish.

Determining the influence of these attributes requires coordination with the resource and regulatory agencies.

15.4.6.1 Structure Type

Given no financial or other restraints, the following structure types in order of preference will maximize fish passage at highway crossings:

- bridges;
- open-bottom culverts;
- countersunk culverts*;
- conventional corrugated pipe with a grade less than 0.5%;
- culverts with sills, baffles or slot orifices on grades between 0.5% and 5.0%; and
- structures with a special, separate fishway.

* *Culvert invert depressed 20% of it's diameter below the streambed and backfilled with bed material resistant to movement at the expected barrel velocities during the design flood.*

15.4.6.2 Fish Movement Type

Three types of fish movements are of concern:

- spawning runs,
- forced movement, and
- seasonal or rearing movement.

15.4.6.2.1 Spawning Run

These runs consist of mature fish returning to the area where they were spawned to deposit their eggs. Timing may be important. Spawning runs for some species are believed to be triggered by a combination of degree days and water temperature. As such, these runs must occur at a particular time.

Some fish species cannot be delayed for any extended period of time without adversely affecting the survival rate of the fry. Biologists for the responsible resource agency can advise on the time frame when fish are migrating.

Given these findings, a highway facility must be designed that is sensitive to the flow characteristics existing in the natural channel reaches upstream and downstream of the culvert. Knowing the magnitudes and distributions of velocity and flow depths existing in the natural channel the culvert itself can be evaluated for a range of culvert sizes to establish a proper selection.

Flow rate determination requires a hydrologic analysis. In some instances, the passage problem is greatly complicated when fish migration corresponds with the period of maximum flow or minimum flow for certain species of migrating fish.

15.4.6.2.2 Forced Movement

This type of movement is forced on fish due to some natural or constructed phenomena. These events may occur due to:

- floods sweeping families of fish and insects out of the steeper headwater regions,
- changes in fish feeding habits,
- lack of suitable feed,
- loss of instream or riparian cover,
- drought, and
- the need to find more favorable water temperatures.

These displaced fish must be able to return to their home reaches to perpetuate the natural diversity of these reaches. These fish are not subjected to the same type of stress as spawners. They can be delayed for an extended period of time at a drainage crossing waiting for flows to subside or increase. However, the entire age group, juvenile through mature fish, should eventually be able to ascend the crossing during some acceptable flow period.

The recommended design method is the same, the discharge being evaluated being a flood or high flow event instead of a lower flow event. The culvert is selected which is sensitive to the flow characteristics existing in the natural channel reaches upstream and downstream of the culvert. Knowing the magnitudes and distributions of velocity and flow depths existing in the natural channel the culvert itself can be evaluated for a range of culvert sizes to establish a proper selection.

15.4.6.2.3 Seasonal or Rearing Movement

This type of fish movement is caused by seasonal climate changes causing fish to vacate a stream reach. Seasonal phenomena, such as streams freezing solid during winter months or incurring severe flow reductions during late summer months, will force fish to migrate to where flows are sufficiently deep and quiescent to sustain a suitable habitat. When spring breakup occurs or flows increase, these fish migrate into the previously vacated reaches for spawning and/or summer feeding. Again, it may be necessary to provide fish passage facilities for the entire age group, fry through mature fish, under these circumstances. Fortunately, as with forced movements, delay is usually not a factor.

15.4.6.3 Temperature Effect

The temperature of the water may have a marked effect on the swimming capability of fish. Fish swimming speeds generally decrease with low temperatures, peak at some optimum temperature, then are reduced sharply at still higher temperatures. Installation of a culvert, even a very long culvert, will have essentially no effect on the temperature of the flowing water in a stream. Moreover the nature of whatever slight influence on temperature is exerted is seen to be in a beneficial direction; shading in the summer and because of the mass of the embankment a stabilizing effect in the winter. Figure 15-2 is a guide where temperature effects are considered important.

See Section 15.4.6.5.4 for more discussion.

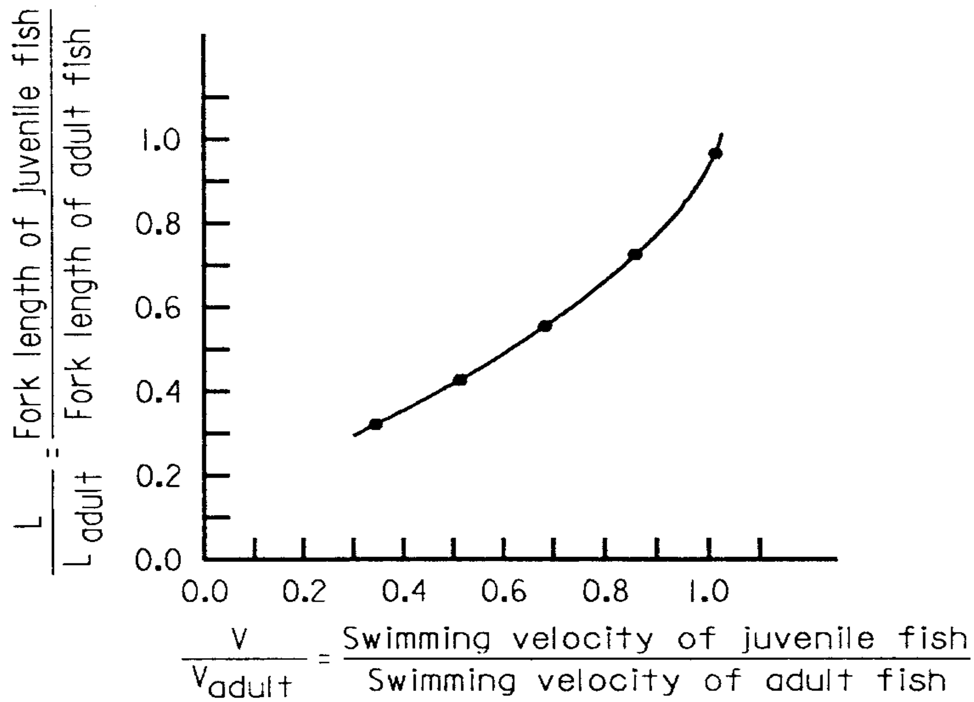
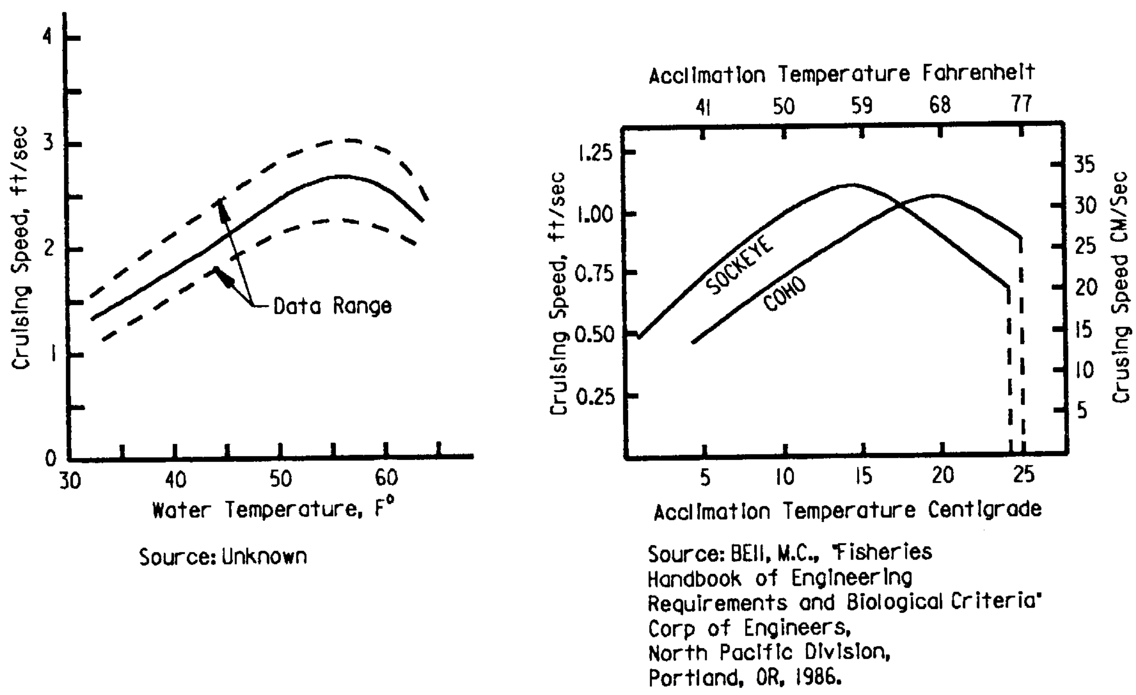


FIGURE 15-1 — Juvenile Fishes Swimming Speed



Source: Reference *(3)*

FIGURE 15-2 — Temperature Effect on Fishes' Swimming Speed

15.4.6.4 Design Flow Depths

Fish passage designs should ensure that the range of depths provided including the minimum depths are compatible and complement the depths prevailing in the adjacent upstream and downstream reaches of the channel.

15.4.7 Fish Passage Culverts

The three geometric elements of a culvert that influence fish migration are the:

- Inlet,
- Barrel, and
- Outlet.

15.4.7.1 Inlet Geometry

- It is desirable that the culvert entrance be slightly submerged or that sufficient backwater and flow depth exist under low flow and normal flow regimes that fish moving upstream do not have to jump to exit. Where unsuitable inlet conditions occur, consider countersinking the culvert.

15.4.7.2 Barrel Geometry

Important elements in designing a culvert barrel for fish passage are:

- Insuring that the flow depths in the culvert barrel are compatible with those found to occur in the adjacent upstream and downstream channel reaches during low and flood flow events;
- Insuring that the velocity distributions in the culvert barrel are compatible with those found in the adjacent upstream and downstream channel reaches during low and flood flow events;
- For long culverts, insuring that the range of velocities encountered in transiting the culvert is compatible with those found in transiting similar lengths of the adjacent upstream and downstream channel reaches.

15.4.7.3 Outlet Geometry

Figure 15-3 shows how to design a outlet wherever there is a need to maintain a pool from which fish can ascend upstream without jumping into the outlet.

Key to the outlet geometry criteria in Figure 15-3 is the downstream or tailwater sill. By adjusting the geometry of the sill and changing the tailwater elevation one can exercise some control over the flow depths and velocities inside the culvert. Figure 15-4 illustrates the elements of the sill. If it is necessary to avoid an excessive sill height, more than one sill may be considered. The sills on Figures 15-5 and 15-6 are shown as rock; other materials may be used, however. Sills are located beyond any expected scour hole (see Energy Dissipator Chapter). Methods of estimating the depth discharge relationship for various sill geometries are discussed later in this Chapter.

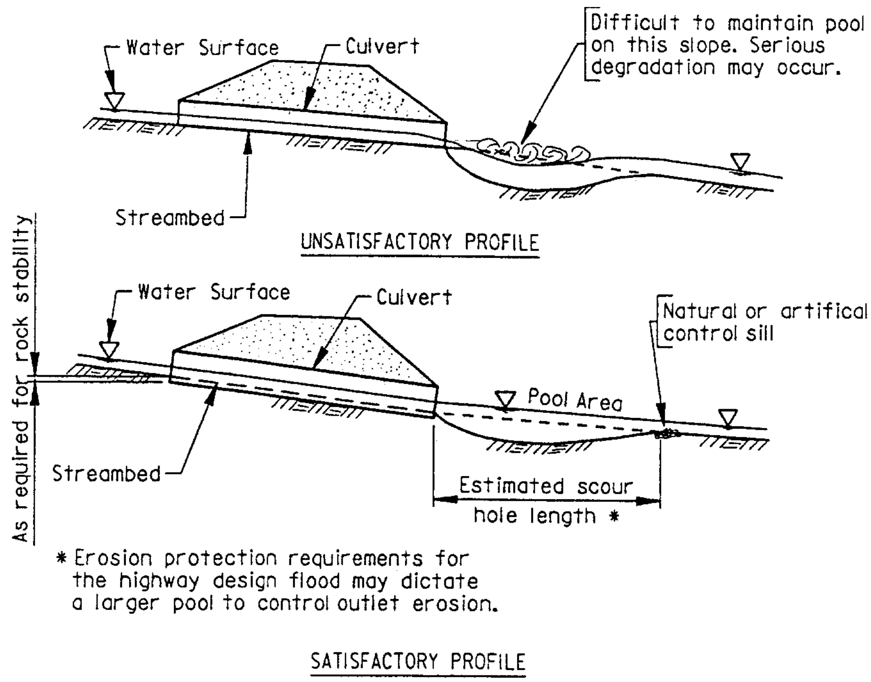


FIGURE 15-3 — Outlet Geometry for Fish Passage

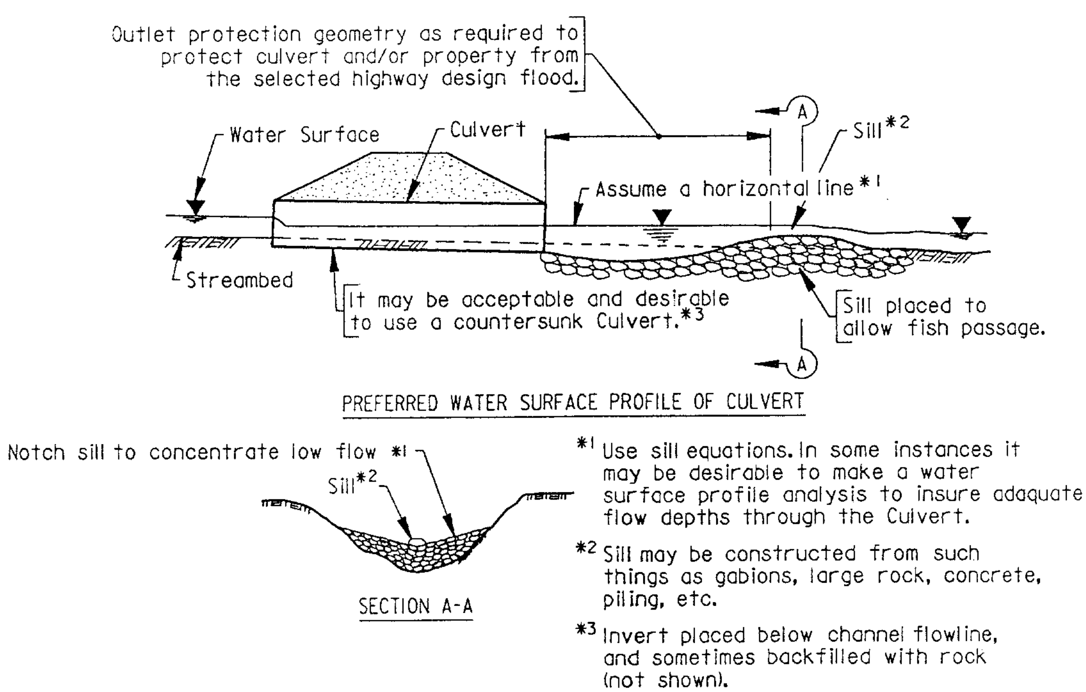


FIGURE 15-4 — Sill Criteria at Culvert Outlet

15.4.8

Fish Passage Culvert and Fishway Types

A distinction should be made between fish passage culverts and culvert fishways. Fish passage culverts are the more common installations that are designed to pass fish at a specific range of discharges and also pass the design flood. Fishways, conversely, are designed to optimize the passage of fish although maximizing the vertical gain over a given distance and operate through a narrow range of discharges. Fishways commonly require bypass or flood relief facilities to account for higher discharges. A fishway might be designed in parallel with a stream so that fish moving upstream leave the stream at a barrier, enter the fishway, move through the fishway, and then re-enter the stream *(2)*.

Six fish passage culverts or fishways are addressed:

- smooth (i.e., invert at streambed level);
- countersunk (i.e., invert below streambed level);
- open bottom;
- sill;
- baffle; and
- slot orifice.

15.4.8.1 Smooth Fish Passage Culvert

For fish passage, all culverts, regardless of material type [Concrete, CMP, HDPE etc.], are considered "smooth" if their inverts are placed at approximate streambed level. See Figure 15-3 (smooth) and compare with Figure 15-5 (countersunk).

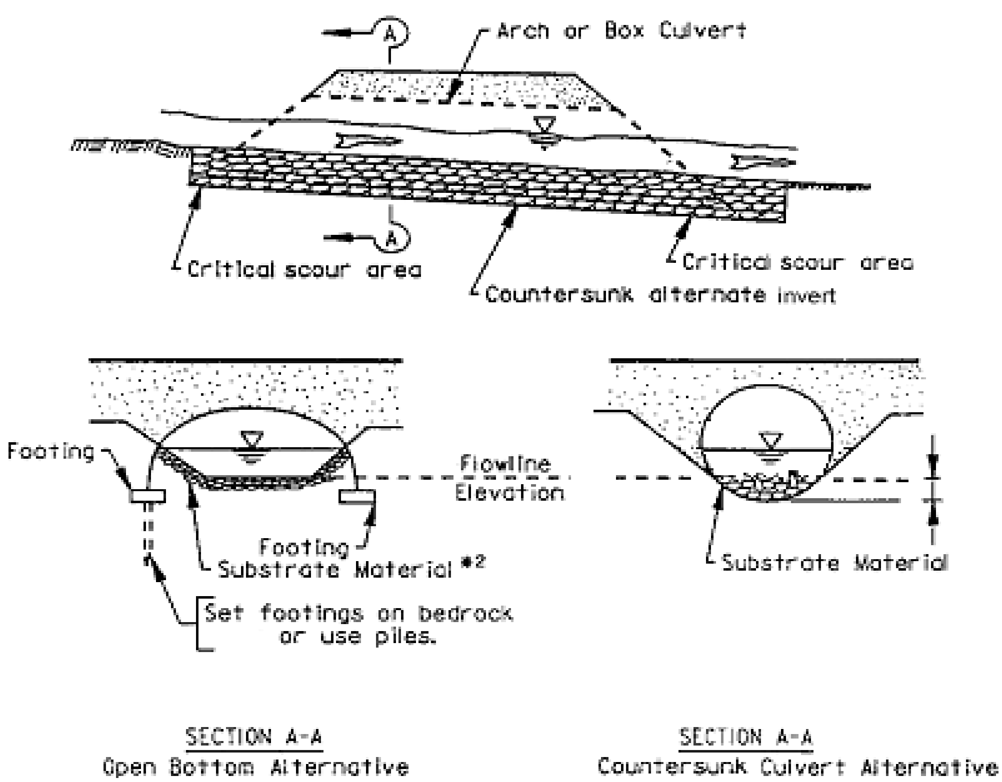


FIGURE 15-5 — Open Bottom for Fish Passage

Where conditions are favorable, an at grade or “smooth” culvert is the most economical and least disruptive culvert to install. Where conditions are less favorable the “smooth” culvert alternative may be unacceptable unless a tailwater sill is employed to obtain compatible flow depths and velocities for fish passage. On steeper slopes, sills alone in the barrel may be inadequate and additional appurtenances will be required; see Baffle Type Fishway and Orifice Type Fishway.

15.4.8.2 Countersunk Fish Passage Culvert

Figure 15-5 shows how a properly sized culvert can be countersunk (depressed) approximately 20% of the culvert diameter below the streambed to:

- Allow a natural substrate to be maintained in the culvert bottom,
- The roughness of the substrate creates quiescent water locations in which fish can rest
- Insures the submergence of the culvert entrance,
- Minimizes scour at the culvert outlet and promotes a stable pool to form that inundates the lower portion of the culvert outlet.

Experience shows that culverts whose inverts have been buried 20% or more of their diameter will easily retain a natural substrate bottom. Where it is not practicable to bury the 20% of the culvert diameter, sills can be periodically placed at the culvert invert to help hold substrate material in place. It should be recognized that during extreme floods, the substrate material is likely to be scoured out from between the sills, and from around any boulders; however during the falling limb of the hydrograph of such extreme events, upstream bed load material normally will be deposited in the culvert, preserving and maintaining the substrate.

Another geometry is possible with multiple barrel culverts. One barrel can be depressed below the streambed and a suitable, scour-resistant substrate material installed as noted above. The other barrel(s) can be raised so as to convey primarily flood runoff beginning at some predetermined discharge; usually the dominant charge.

15.4.8.3 Open Bottom Fish Passage Culvert

A culvert substrate similar to that in a natural channel will facilitate fish passage. Figure 15-5 provides guidelines and criteria for this geometry. Consider this alternative only where:

- the selected culvert design flood is within an incised channel,
- the footings can be substantially protected from scour, and
- hazardous headcutting will not occur.

With the open bottom culvert alternative, the designer should verify the culvert stability during the design event. This is to avoid an unacceptable flood hazard from scoured footings.

15.4.8.4 Sill Type Fish Passage Culvert

Sills or weirs as shown on Figures 15-8 and 15-9 are continuous across the culvert whereas baffles, although similar, have some type of opening through them as shown in Figures 15-10, 15-11 and 15-12 in Section 15.4.9.5. Baffles are addressed later.

The primary design features to be considered in the design of a sill type fish passage culvert are:

- sediment and debris,
- obtaining a satisfactory flow regime,
- sill hydraulics,
- sill crest type (straight or notched),
- bed load considerations, and
- potential flood hazards.

15.4.8.4.1 Sediment and Debris

Normally, vertical sills spaced at regular intervals are placed on the culvert floor perpendicular to the culvert centerline thus forming a series of pools and overfall weirs; see Figure 15-6. Where sediment and debris is a concern, consider a sloped sill fishway.

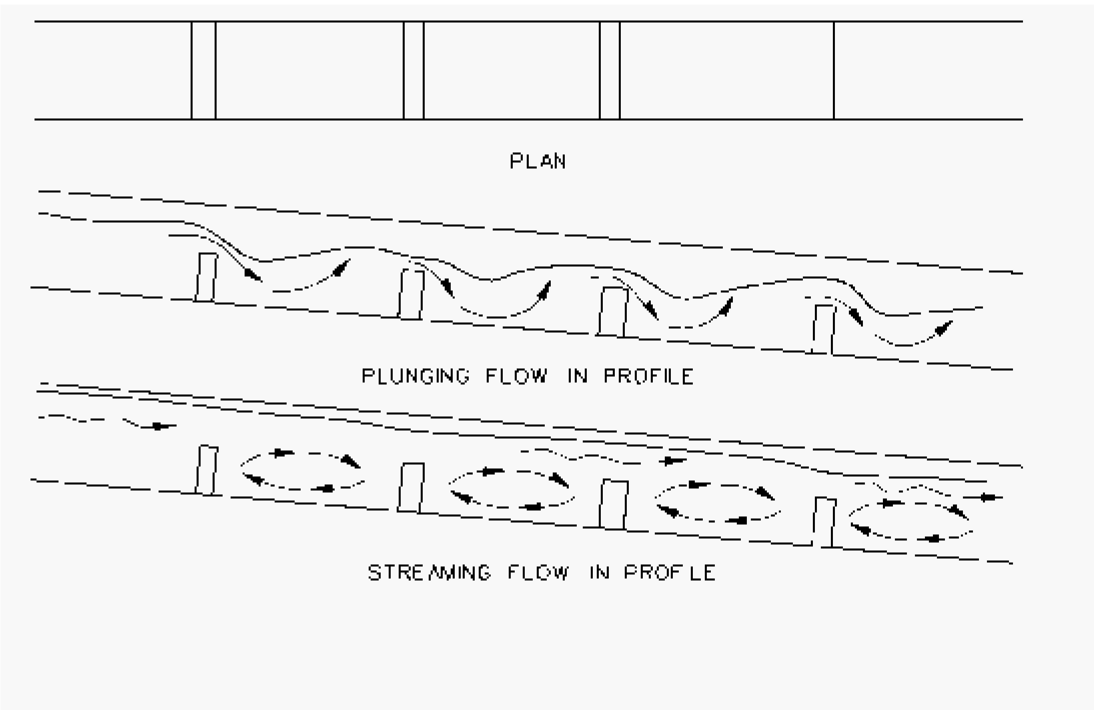


FIGURE 15-6 — Plunging and Streaming Flow in Sill Fishway

15.4.8.4.2 Flow Regimes

A critical consideration is the two distinct flow regimes that can occur with sills:

- plunging, and
- streaming

These flow regimes are illustrated in Figure 15-6. Plunging flow drops from pool to pool in a cascading fashion. Each pool is sized to afford the fish a relatively quiescent resting area prior to each ascent of a sill (or passage through a baffle or slot orifice). As discharge increases, streaming flow occurs that skims over the weir tops at a higher velocity and is unsatisfactory for fish passage. The roughness characteristics of sills during streaming flow are not fully understood, making flood capacity determinations difficult.

Sill-type fish passage culverts are less desirable than the previous types because they can reduce flood conveyance capacity and require frequent inspection and maintenance. They are more appropriate for use in fishway installations where bypass discharge is accounted for.

15.4.8.4.3 Sill Hydraulics

Hydraulically, a sill functions as a weir when operating in the plunging mode. Approximate overflow velocities may be estimated by applying the energy equation between the surface pool upstream of the sills and the water surface elevation downstream of the sills. The sill crest may be:

- sharp, or
- rounded.

Rounded sills have the upstream edge of their crest rounded whereas the sharp edge sills do not (compare Figure 15-11 with Figure 15-16 in Section 15.4.9.5). Rounded sills exert a much lower drag force per unit frontal area than is exerted by sharp edged sills. However, rounded sills are less effective in reducing barrel velocities in culverts. When used, the radius of rounding is equal to the thickness of the sill (see inset on Figures 15-13 through 15-18). Although this rounded shape is desirable for hydraulic reasons, for reasons related to economics and ease of construction, the square edged, rectangular sills are preferred.

For the present, design curves for only rectangular culvert barrels are available. Six design curves for concrete box type culverts with a sill type fishway are provided as Figures 15-13 through 15-18, which apply to a sill shape that is rectangular in cross-section with sharp edges. This is the most commonly used shape. These Figures represent box culvert shapes ranging from a narrow, rectangle shape having a width equal to 0.5 times the height, to a wide rectangle shape having a width equal to 2.0 times the height.

Figures 15-16 through 15-18 are for box culverts having the same barrel shape as Figures 15-13 through 15-15, but with rounded sill crests instead of sharp edged crests. The rounded crests, although improving the hydraulic efficiency, are more costly. Although the rectangular shape is usually less costly to construct, the improved sill shape might be preferable for retrofitting existing culverts to improve the fish passage to not sacrifice a large amount of design flood capacity.

Figures 15-13 through 15-18 use the Darcy f_T as a variable. This value may be used directly in the outlet control headwater equations of the Culverts Chapter by solving for the losses in the following manner:

$$H = [1 + k_e + (f_T L_a)/(4R_H)]V^2/2g \qquad (15.1)$$

where:
- H = total energy loss through a culvert barrel in outlet control, ft
- k_e = entrance loss coefficient
- f_T = Darcy f_T value from Figures 15-13 through 15-18
- L_a = culvert length, ft
- R_H = full flow hydraulic radius, ft
- V = mean velocity of flow, ft/s,
- g = gravitational acceleration, ft/s^2

The only other modification to the usual outlet control calculations is that a sill (or baffle) should be placed at the culvert outlet. Consideration must be given to computing and using the critical depth (d_c) as the elevation of the hydraulic grade line at the culvert outlet (h_o). The distance from the culvert flowline invert to the water surface, d'_c, would equal d_c from the appropriate chart in the Culverts Chapter plus the height of the sill (or baffle), h. Thus:

$$d'_c = d_c + h \tag{15.2}$$

where d'_c cannot exceed the height of the barrel, D, and:

$$h_e = (d_c + H + D)/2 = (d'_c + D)/2 \tag{15.3}$$

or tailwater, TW, whichever is larger.

If a sill or baffle is not placed at or near the outlet of the culvert, the above modifications are unnecessary, and $h_o = (d_c + D/2)$.

In addition to sharp edged or rounded, sill crests may also be:

- straight, or
- notched.

15.4.8.4.4 Straight Sills

Straight sills are level across the top and, as such, make no special provision for fish migration during low-flow periods. With a straight sill, this requires that the overflow velocity and depth be acceptable at all points along the crest at some period of time during migration periods.

15.4.8.4.5 Notched Sills

These sills have a notch in their crest rather than being straight. They are used where a straight sill does not provide acceptable low-flow hydraulics for fish migration. These notches are less than the full height and width of the sill. Generally, the effect of the notches can be neglected in the computations of hydraulic resistance when designing a culvert to meet highway needs. This is because of the following:

- Alternating the notch transverse location from sill to sill to enhance the fish migration hydraulics precludes a more efficient, continuous path for the flow through the notches.

- The secondary currents and turbulence from such notches will probably equal or outweigh any limited conveyance benefits.

15.4.8.4.6 Bed Load Considerations

Bed load deposition in the pools limits the effectiveness of sills, baffles or slot orifice fishways. The bed material carried in a steep stream may fill the pools between the sills (or baffles) resulting in streaming flow even at the lower migration discharges. It is not economical to clean the pools because the work must be done by hand due to the low head room and/or interference with mechanical equipment from the sills or baffles being on the floor. Accordingly, sills (or baffles) should not be used where bed load problems are expected.

A big reduction in flow velocity for small discharges can be realized along with minimal bed load problems if the culvert is:

- on a moderate slope,
- oversized hydraulically, and
- subject to gravel size or smaller bed load so that the sills are self cleaning.

Given the foregoing, sills (or baffles) may be considered unless the bedload is of such size that it can accumulate in areas adjacent to the sills. Where this may occur, they should not be used because the roughened area will fill, and the sills will not materially reduce the velocity or provide resting pools for migrating fish.

15.4.8.4.7 <u>Potential Flood Hazard</u>

An undesirable feature with any type of floor sill (or baffle) may be the loss of hydraulic efficiency during passage of the culvert's design flood. For culverts operating with barrel control, efficiency is defined as the ratio of the depth of flow in a culvert operating without sills (or baffles) divided by the depth of the flow for the same discharge and culvert barrel dimensions but with sills (or baffles) in place.

This is not a problem with new construction because provision can be made for this lost efficiency by using a larger culvert. Loss of hydraulic efficiency is a more important consideration when existing culverts are modified. As an example, consider a 6-ft high box culvert operating with barrel control that is sized to carry a particular discharge with a headwater of 6 ft. If the culvert is converted to a fishway by installing 1-ft high sills (or baffles), the headwater for the culvert would have to be approximately 8 ft for this same discharge. This headwater is 2 ft higher than that expected based on the original design. In some situations, 2 ft of additional headwater may inundate valuable land, buildings and/or overtop the highway fill resulting in:

- potential liability for flood-related property damage,
- damage to the highway,
- increased potential liability for flood related traffic hazards, and
- possible loss of the culvert and/or highway.

Consider loss of efficiency in light of the foregoing hazards when modification of an existing structure is proposed. New structures can be designed recognizing this loss of hydraulic efficiency.

For wide sill (or baffle) type culverts with fishways that are operating with inlet control, the increase in headwater can be roughly approximated using weir formulas. As an example, a 6-ft high box culvert operating under entrance control will admit approximately 42.5 ft^3/s per foot of width of culvert; see the Culverts Chapter. If a 1-ft high sill (or baffle) is constructed across the entrance of the culvert and a standard sharp edge weir equation is used for computing discharge, the baffled culvert will admit only 33.5 ft^3/s per foot of width. Thus, for the same headwater conditions, the baffled culvert would have to be widened approximately 27% to accommodate the same discharge as the original box culvert with no change in headwater. Accordingly, consider the following for culverts that will have sill (or baffle) fishways:

- *New Culverts* — These must be designed to pass the selected design discharge at an allowable headwater depth that avoids a flood hazard with full consideration being given to the sill, baffle or slot orifice effect.

- *Existing Culverts* — These must not be modified if they unacceptably increase the existing flood hazard.

With existing culverts, if the flood hazard frequency would be increased because of retrofitting for a fishway, additional opening must be provided so as to preclude this hazard.

15.4.8.5 Baffle-Type Culvert Fishway

There are three basic baffle types:

- alternating pair,
- offset, and
- slot orifice.

As with sill type fishways, it is necessary to evaluate flow types, bed load and potential flood hazards. These factors are evaluated similar to sills. However, recognize that the fishway hydraulics are different.

15.4.8.5.1 Alternating Pair

Alternately paired baffles, illustrated in Figure 15-8, have not always proven effective. During low flows, depths in successive pools are below minimum depth for fish passage and extremely turbulent, unstable flow patterns unsuitable for fish passage occur during high flows. This type is included herein only to alert the designer should others suggest that it be used. If it is used, the hydraulics are computed the same as sills except that corrections are required.

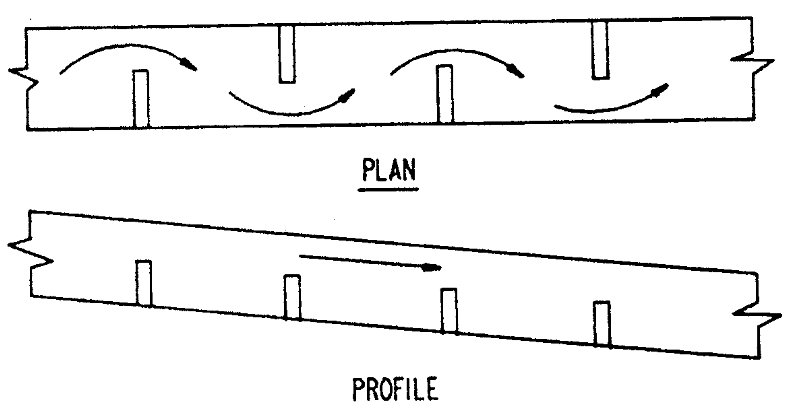


FIGURE 15-8 — Alternating Baffled Fishway
(not recommended)

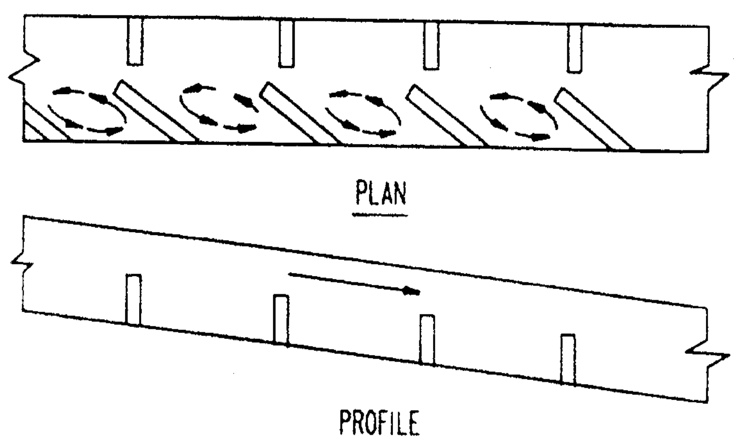
15.4.8.5.2 Offset Baffle

The offset baffle system works most effectively where only small sizes of bedload occur. The system is shown in Figure 15-9.

FIGURE 15-9 — Offset Baffled Fishway
(recommended for small bed load material)

Throughout a large range of flow depths, a counter-clockwise roll of relatively quiescent water forms in the region below the crest of the baffle; i.e., in the apex between the angled baffle and the wall. This roll affords a resting area for the fish as they make successive advances upstream through the gap between the baffles. Offset baffles also have better self-cleaning characteristics for small sizes of bed material. Conversely, the strength of circulation required to sweep out bedload material several inches in diameter results in an unsuitable resting area for migrating fish.

The hydraulics are the same as for sills except that some correction in the hydraulics for



alternating or offset baffles is justified. This correction is made by modifying the baffle spacing parameter, λ/D, before entering Figures 15-13 through 15-18. This is done by multiplying the actual baffle spacing ratio, λ/D, by the ratio of the barrel width (b) to the baffle length (l). The modified spacing ratio would be λ/D (corrected) = (λ/D (actual)) (B/l).

Do not modify the baffle height parameter to compensate for alternating baffles.

It is acceptable to use a baffled fishway either within the culvert or as a facility separate from the culvert depending on costs and whether other acceptable alternatives exist. Figures 15-10 and 15-11 illustrate the more common baffled fishways and their relative acceptability.

Although for a slot orifice fishway, Figure 15-10 illustrates how the baffled and sill-type fishways may be included inside a culvert. However, the culvert inlet geometry must allow an adequate flow rate into the fishway so that it is functional during periods of low flow.

15.4.8.5.3 Slot Orifice Opening

Slot orifice fishways are used only with a rectangular shaped channel. They are similar to the other baffled fishways, except that they have a series of full-depth vertical slot orifices arranged in a systematic pattern within a separate low flow channel located along one side of a culvert wall (either inside or outside). Figure 15-10 shows one of several acceptable alternative slot orifice fishway geometries for a culvert. The fishway may be constructed outside the culvert barrel but monolithically adjacent to the exterior culvert wall. A combination of these two arrangements, where the outside segment of the fishway enters the culvert through the culvert's exterior wall, is another acceptable alternative.

A slot orifice fishway is more costly than the other sill or baffle types. Generally, long culverts (> 150 ft) with no provision for fish migration can be used on grades on the order of 0.5% or less to facilitate small fish migration. However, with a slot orifice type fishway, culverts may be used on slopes in the range of 5% or 6% provided that:

- it is shown that there will be a minimal decrease in hydraulic efficiency for the culvert's design and review discharge, and
- the culvert is operating in inlet control at these same discharges.

The slot orifice alternative is a proven fishway with two distinct advantages:

- It provides stable, low-velocity flow conditions for a wide range of headwater and tailwater depths.
- It is relatively self cleaning.

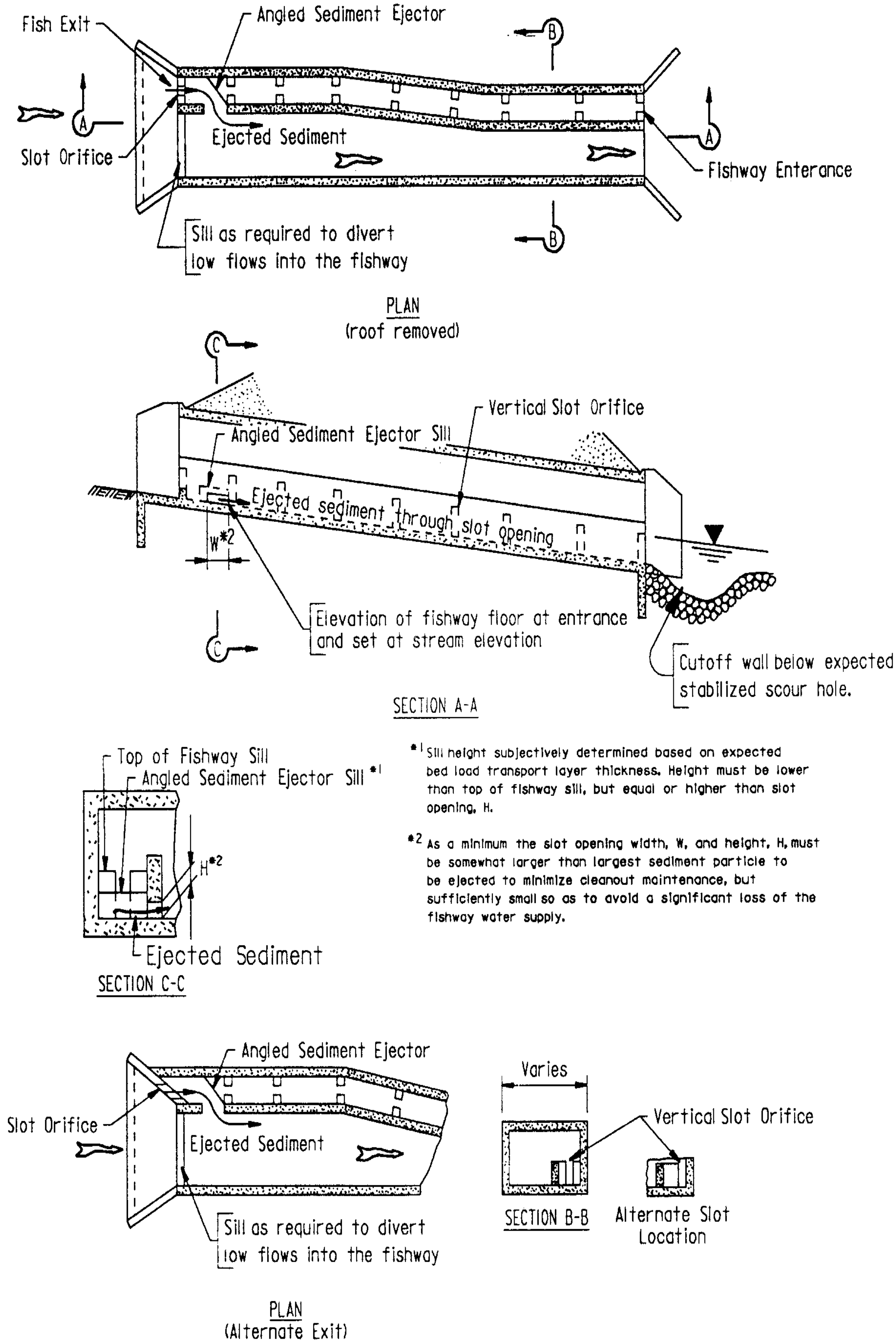


FIGURE 15-10 — Slot Orifice Fishway (acceptability unknown)

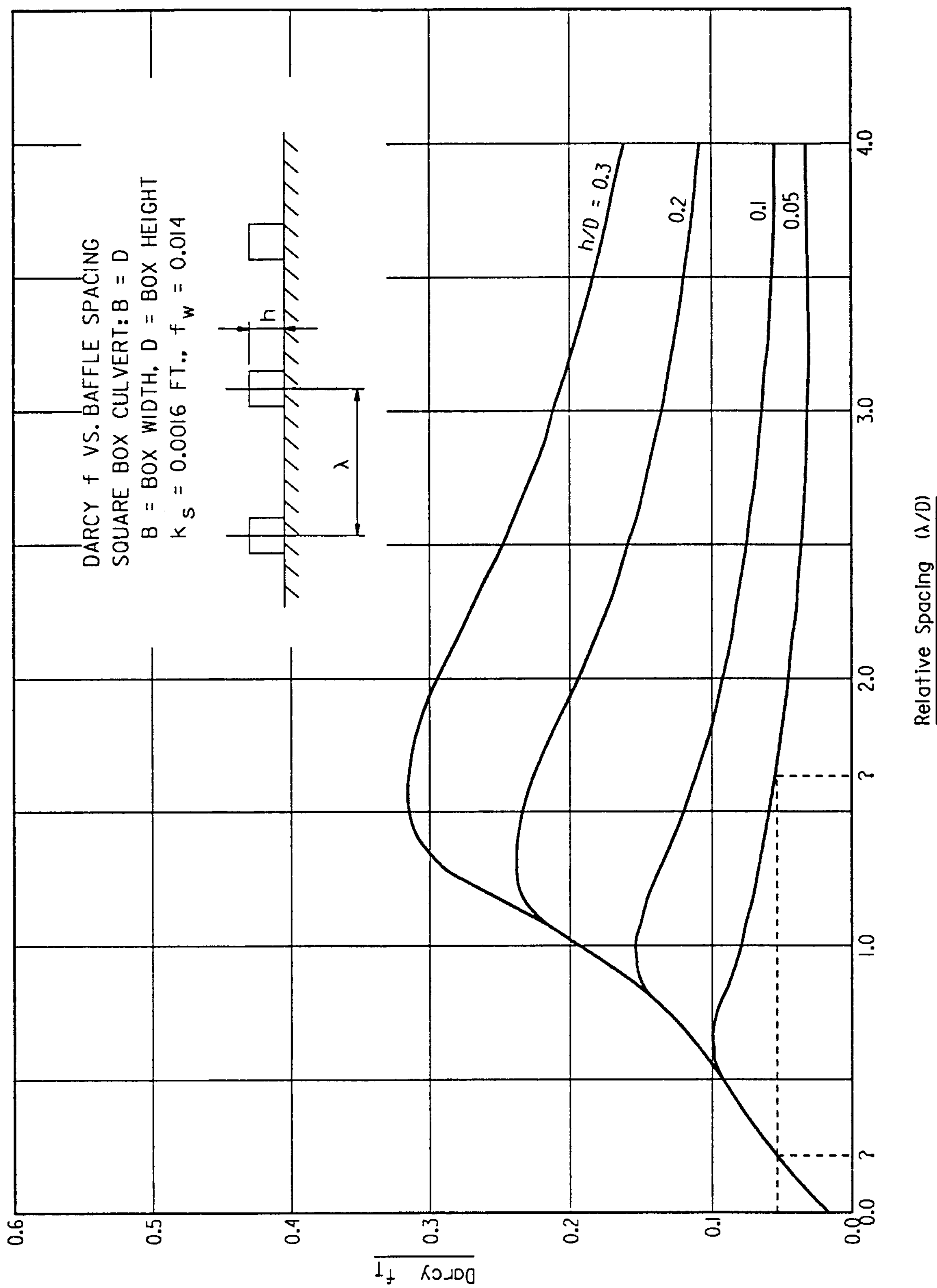


FIGURE 15-11 — Sharp Edge Baffle Spacing vs. Friction Value (B = D)

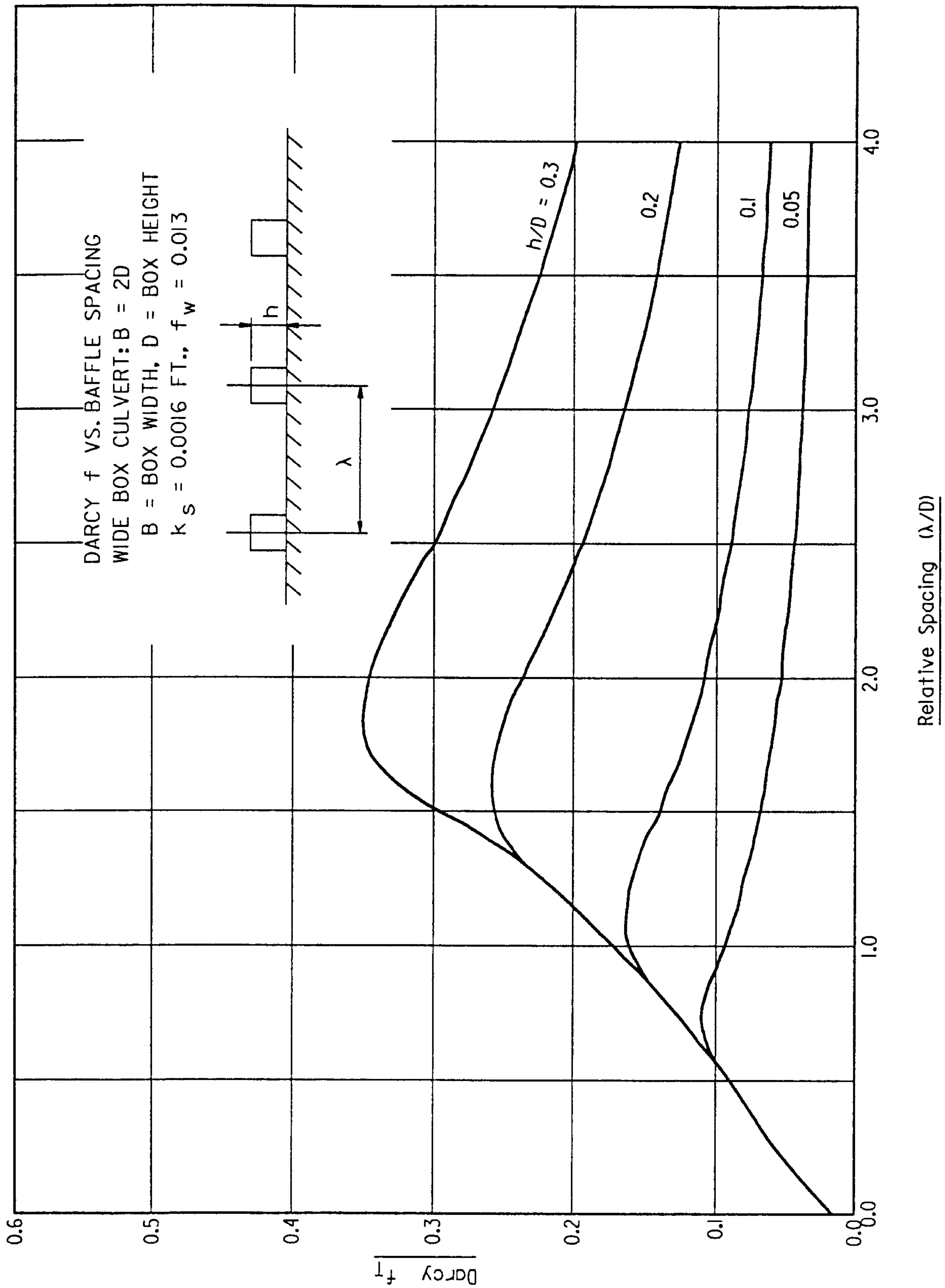


FIGURE 15-12 — Sharp Edge Baffle Spacing vs. Friction Value (B = 0.5D)

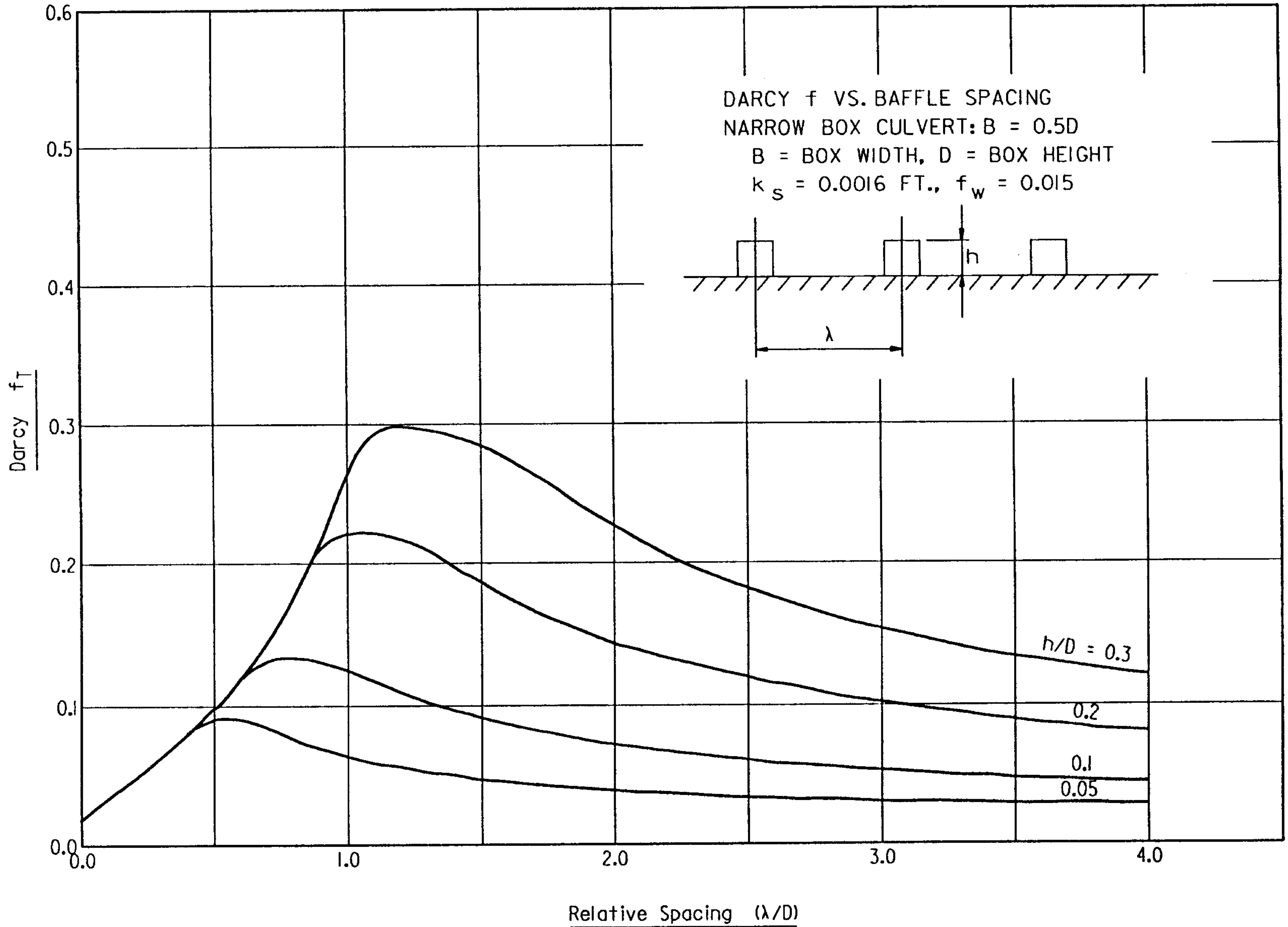


FIGURE 15-13 — Sharp Edge Baffle Spacing vs. Friction Value (B = 2D)

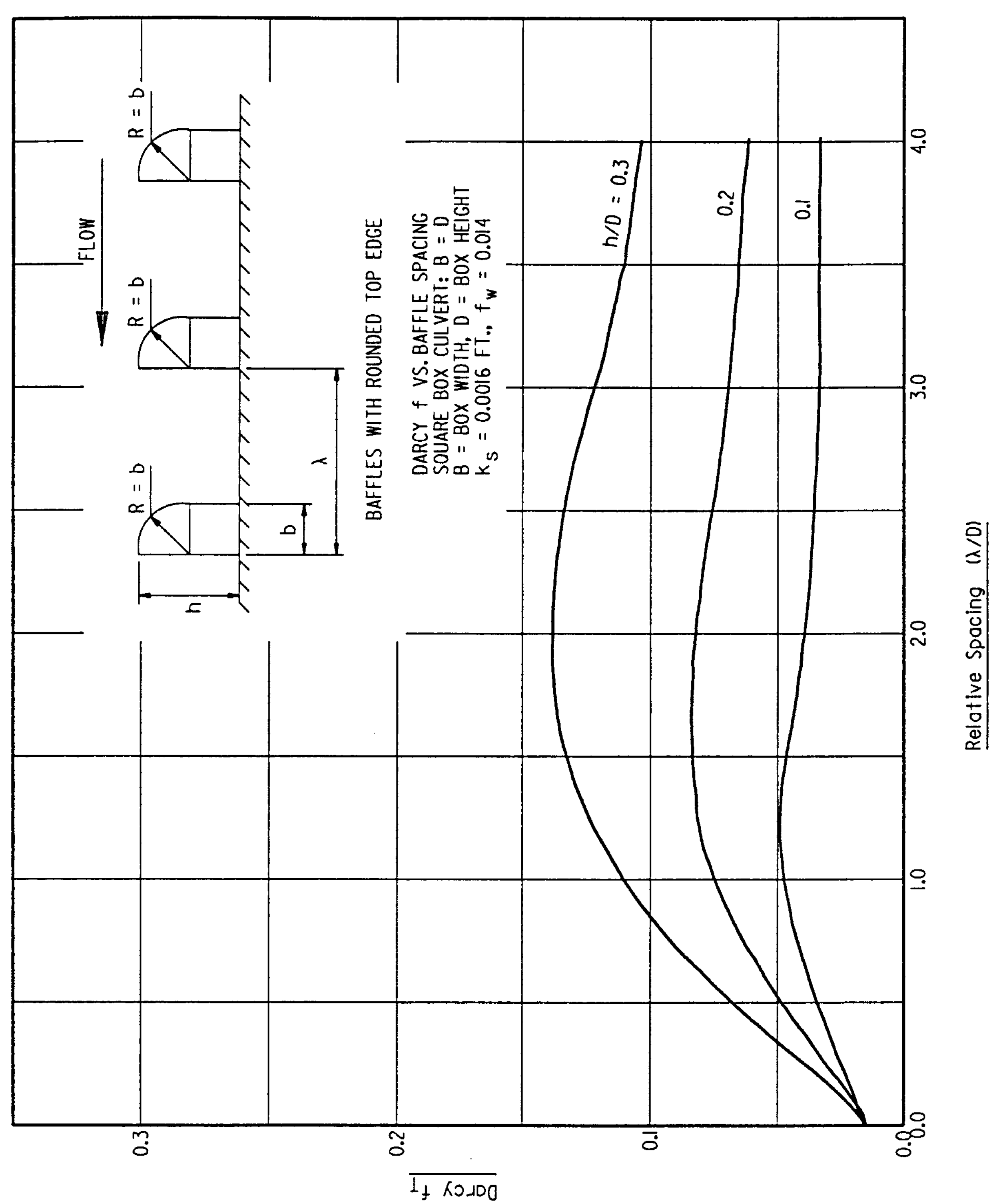


FIGURE 15-14 — Rounded Edge Baffle Spacing vs. Friction Value (B = D)

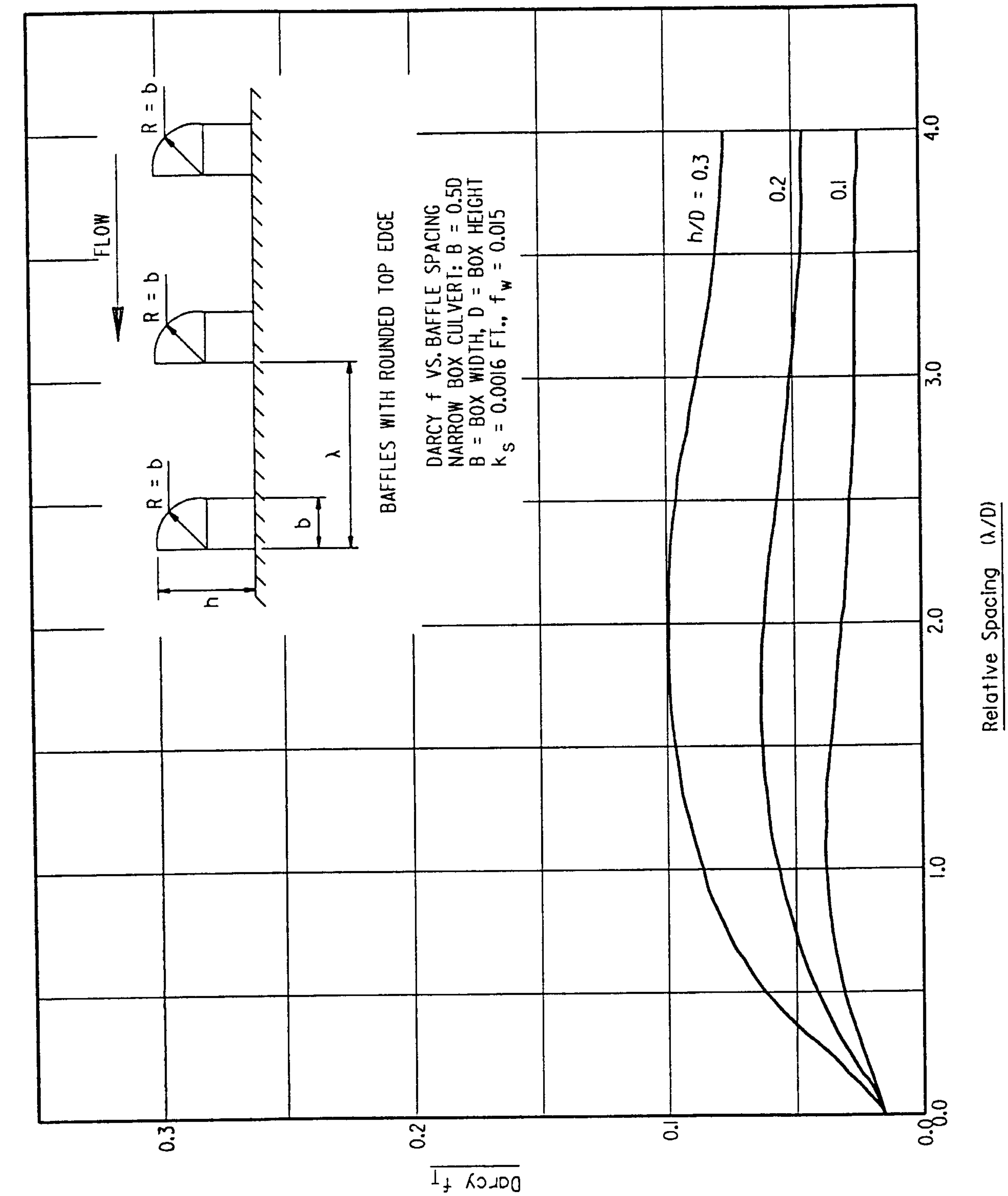


FIGURE 15-15 — Rounded Edge Baffle Spacing vs. Friction Value (B = 0.5D)

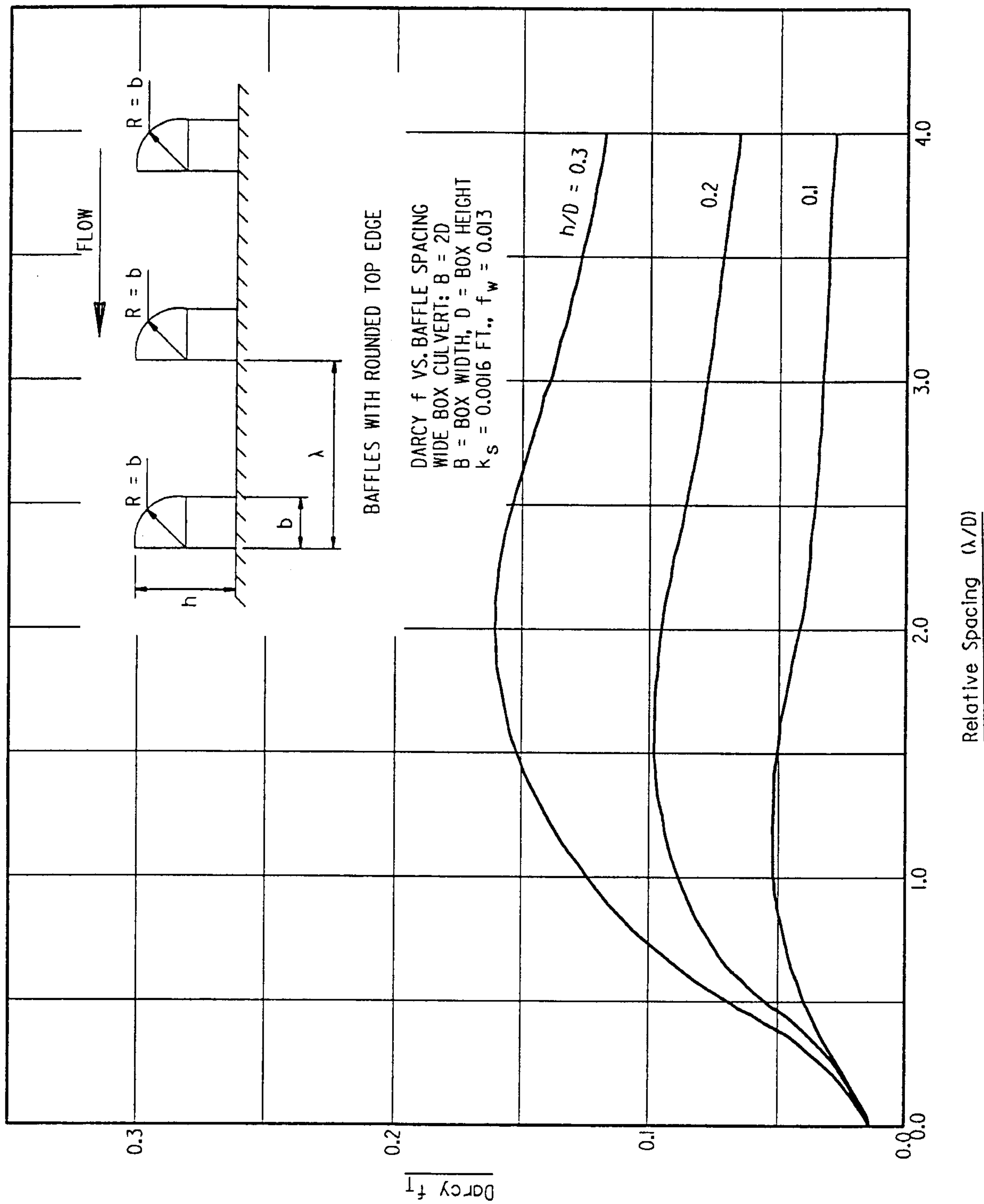


FIGURE 15-16 — Rounded Edge Baffle Spacing vs. Friction Value (B = 2D)

The fishway exit (at the upstream end of the culvert) is constructed with one of the alternatives as shown in Figure 15-10. As with other baffled and sill type fishways, it is essential that sufficient flows pass through the fishway during periods of low flow. On steep grades the hydraulically critical cross section is the same as with the sill or baffled culvert — at the entrance (i.e., inlet control). As suggested by Figure 15-10, at some distance downstream from the entrance (approximately two or three times the height of the box culvert), a monolithic exterior fishway may be brought back into the culvert barrel and located adjacent to the exterior culvert wall. An acceptable alternative to this geometry is where the culvert could be narrowed as shown on Figure 15-10 but, again, this is acceptable only where inlet control occurs (see Culverts Chapter). The effect of this is to constrict the flow and raise the water surface in the narrowed portion of the culvert. With inlet control, the fishway may thus occupy a portion of the narrowed culvert barrel downstream from the wider entrance section. This is provided that the headwater level upstream from the culvert will not be affected by the fishway; i.e., the entrance conditions for the culvert still controls the upstream headwater. This would not occur with culverts operating in outlet control; as such, culverts operating in outlet control do not employ this geometry unless acceptable headwater depths are obtained.

There are two slot orifice design procedures. The selected procedure is a function of the expected culvert:

- headwater, and
- tailwater.

HEADWATER EQUALS TAILWATER. If the depth of water upstream of a slot orifice fishway exit H_i (Figure 15-17) is approximately equal to the tailwater depth, T_1, downstream from the fishway, the total drop in water surface between headwater and tailwater should be divided by the number of orifices to obtain the headwater differential (ΔH) for each orifice with the discharge through the orifice being estimated using the known tailwater depth and Figure 15-18.

HEADWATER NOT EQUAL TO TAILWATER. Where tailwater depth and headwater depth are decidedly unequal, the tailwater depth and the headwater differential (ΔH) through each orifice will vary in a systematic but unknown manner.

Divide the culvert fishway into two parts — the culvert:

- entrance, and
- barrel.

As shown on the sample computation form of Figure 15-19, apply the momentum equation to a control volume that extends from the fishway side of the entrance weir, H_1, to the fishway side of weir, T_i. Include the:

- hydrostatic pressure force terms,
- momentum flux terms for each end section of the control volume,
- appropriate drag force terms for the slot orifices, and
- gravity component of the control volume.

Drag coefficients for slot orifices range from 0.6 to 0.85 for culvert slopes ranging from 0% to 5±%. These coefficients are based on slot orifices having longitudinal spacings of 4, 5 and 6 times the fishway width, B.

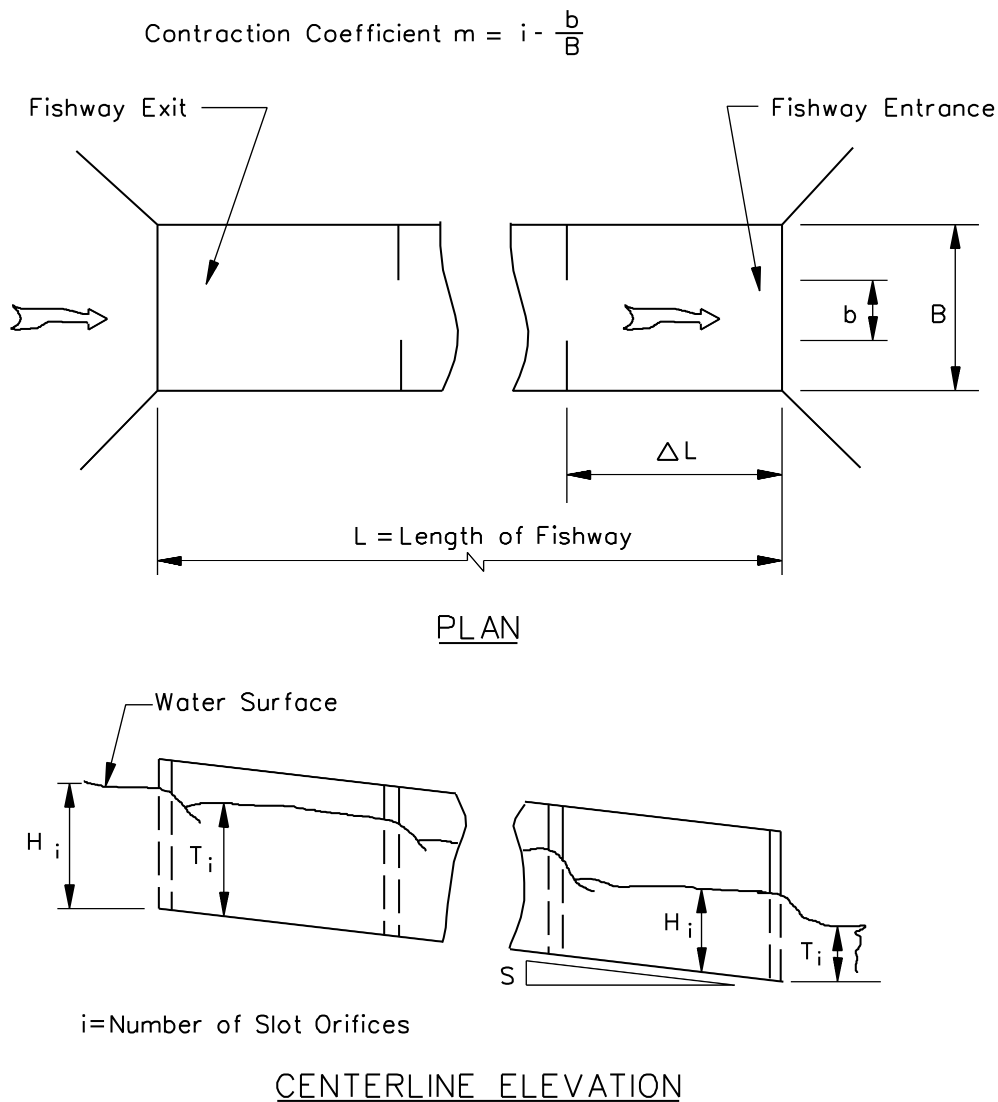


FIGURE 15-17 — Definition Sketch for Slot Orifice Fishway

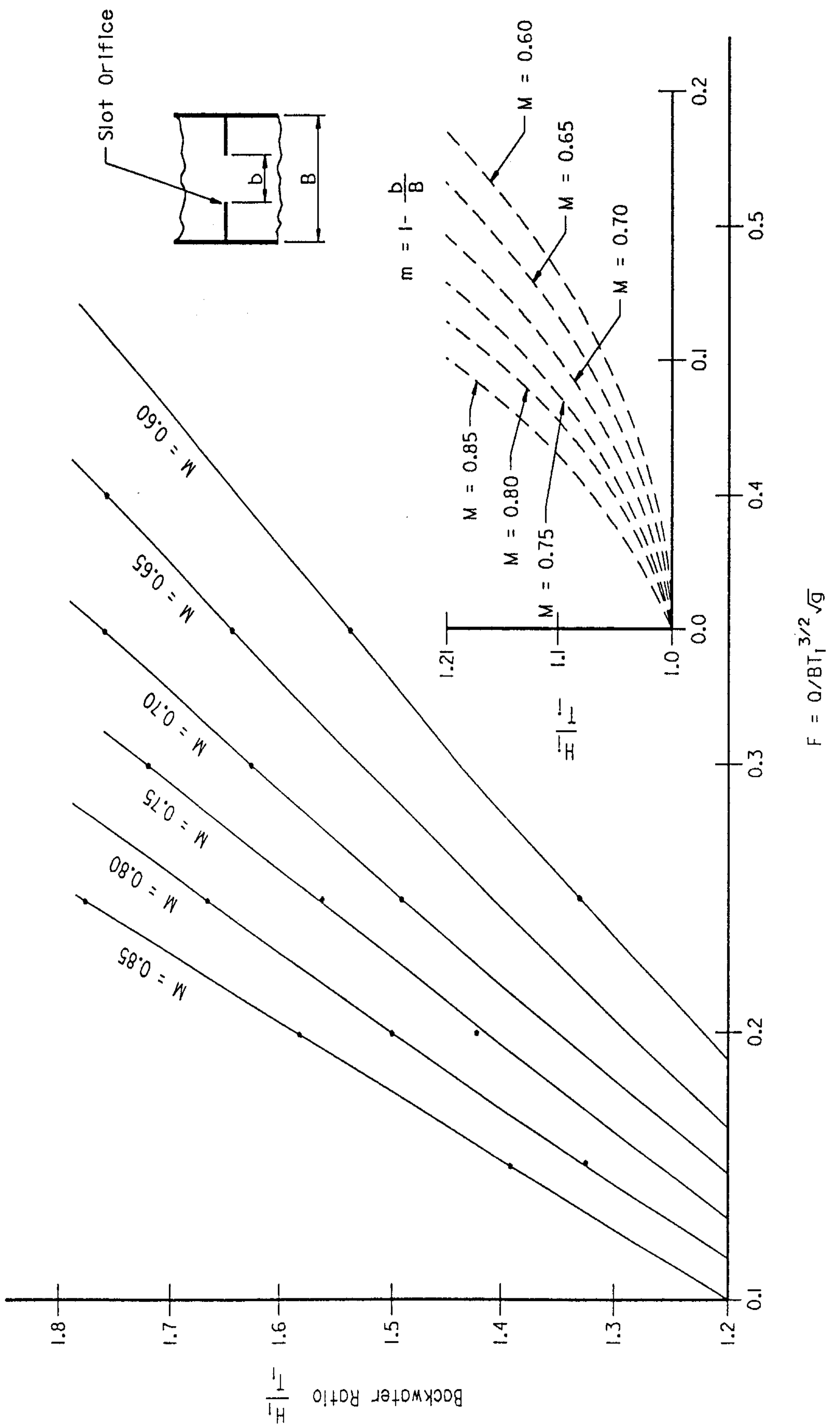
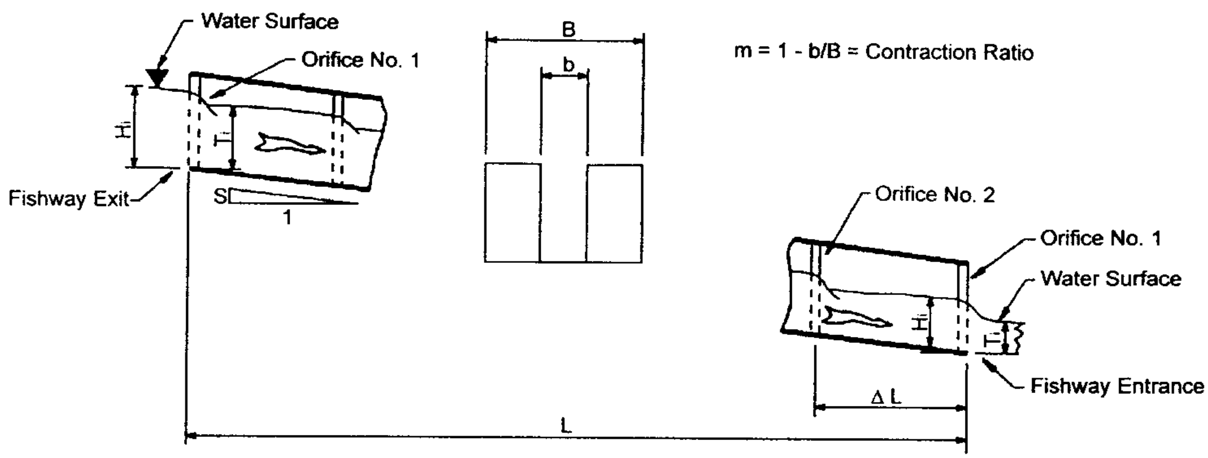


FIGURE 15-18 — Rating Curve for a Slot Orifice



ϕ =	m_s =	Q =
L =	i =	Q/B (3.13) =
S =	ΔL =	S (ΔL) =
B =	T_i =	
m =	H_i =	

1	2	3	4	5	6	7	8
Orifice No. i	T_i (ft)	$T_i^{1.5}$ ($ft^{1.5}$)	$\frac{Q}{B(g)^{0.5}\,(T_i)^{1.5}}$ (—)	$\frac{H_i}{T_i}$ (—)	H_i (computed) (ft)	$T_{i+1} = H_i - S(\Delta L)$ (ft)	$V_i = Q/(B(1-m)+i)$ (ft)

FIGURE 15-19 — Computation Sheet for Slot Orifice Fishway Design

The fishway entrance orifice is designed separately. Rating curves for unskewed slot orifices as a function of the contraction ratio, m, and headwater-tailwater ratio, H_i/T_i, are provided on Figure 15-18. With the aid of these rating curves and the foregoing drag coefficients, the momentum equation is solved by trial and error to determine the throat velocity at the fishway entrance.

In some installations, it may be necessary to install the upstream fishway exit in a skewed wall. This is done as shown in Figures 15-12, 15-22 and 15-23. With a skewed orifice, the rating curve is a function of the skew angle and the contraction ratio, m, and the headwater-tailwater ratio, H_i/T_i.

The design curves of Figures 15-24 through 15-27 are applicable for:

- m values of 0.6 to 0.85,
- skew angles of 30° to 75°, and
- H/T_1 ratios from 1.0 to 1.4.

The design of a fishway with a skewed slot exit is similar to the design procedure of any other slot orifice. The exception is that the appropriate rating curve for the skewed slot orifice (Figures 15-24 through 15-27) is used at the exit in lieu of the curves on Figure 15-18.

When a fishway exit is constructed in a skewed abutment wall, the entrance shown in Figures 15-22 and 15-23 is used. The slot orifice is essentially perpendicular to the centerline of the fishway so that the design procedure shown on Figure 15-19 is suitable. H_i is assumed to be equal to the headwater depths at the culvert entrance for the selected range of fish migration discharges.

A trash rack is constructed across the opening in the abutment wall to prevent debris from blocking the orifices. A sill as shown on Figure 15-10 is used to ensure that low flows will have a better opportunity to be routed through the fishway to provide optimum fish passage conditions during these periods. Care is required to ensure that the fishway is placed on that side of a culvert that is less likely to incur deposition problems such as occur at the inside of a bendway.

15.4.8.6 Slot Orifice Fishway Culvert

An untested orifice fish passage structure for round or arch pipe is shown in Figure 15-26. Maximum slot velocities of 2 ft/s or 3 ft/s should be attainable for culvert slopes of 5% or 6% with this geometry.

The fishway exit shown in Figure 15-27 is a commercial inlet product modified to allow fish to return to the upstream channel further upstream from the culvert inlet. This is to try to prevent exiting fish from being swept back through the culvert. This might occur if the fish emerge from the fishway into the high-velocity and turbulent zone sometimes found at culvert entrances.

The placement of the support bracket down the center of the culvert divides the flow and provides a deeper trough of water through the fishway during low-flow conditions. The fishway is open at the top and bottom to provide:

- light, where necessary;

- maintenance access;

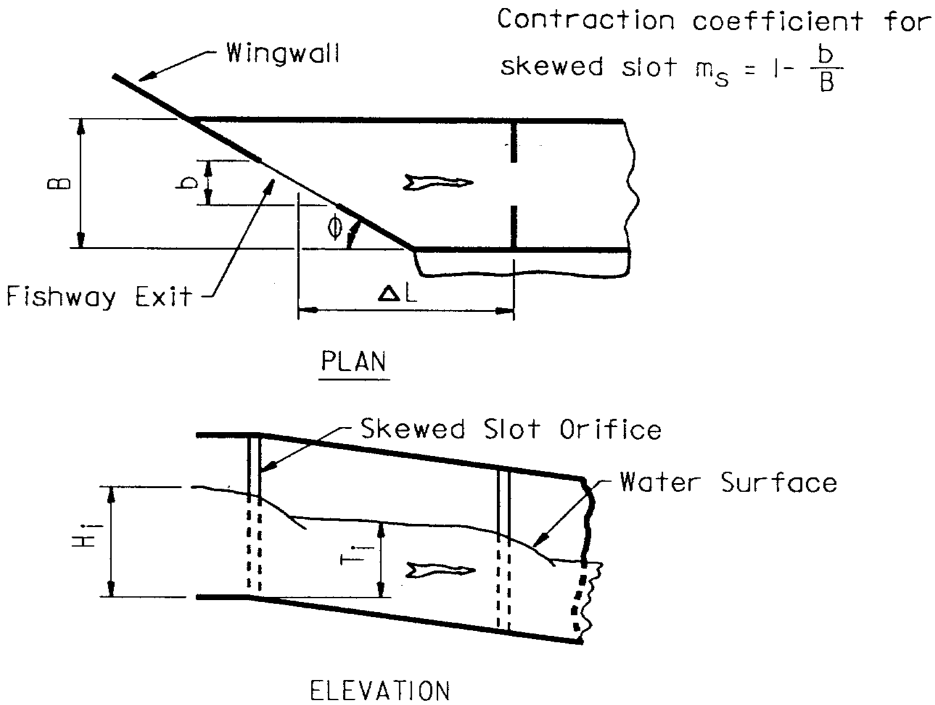


FIGURE 15-20 — Definition Sketch For Skewed Slot Orifice Fishway Exit

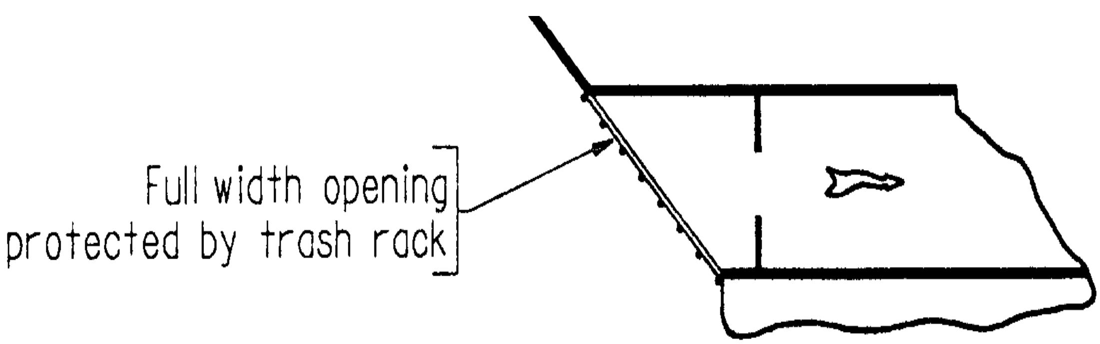


FIGURE 15-21 — Preferred Entrance Arrangement For Fishway Exit Construction In Culvert Wingwall

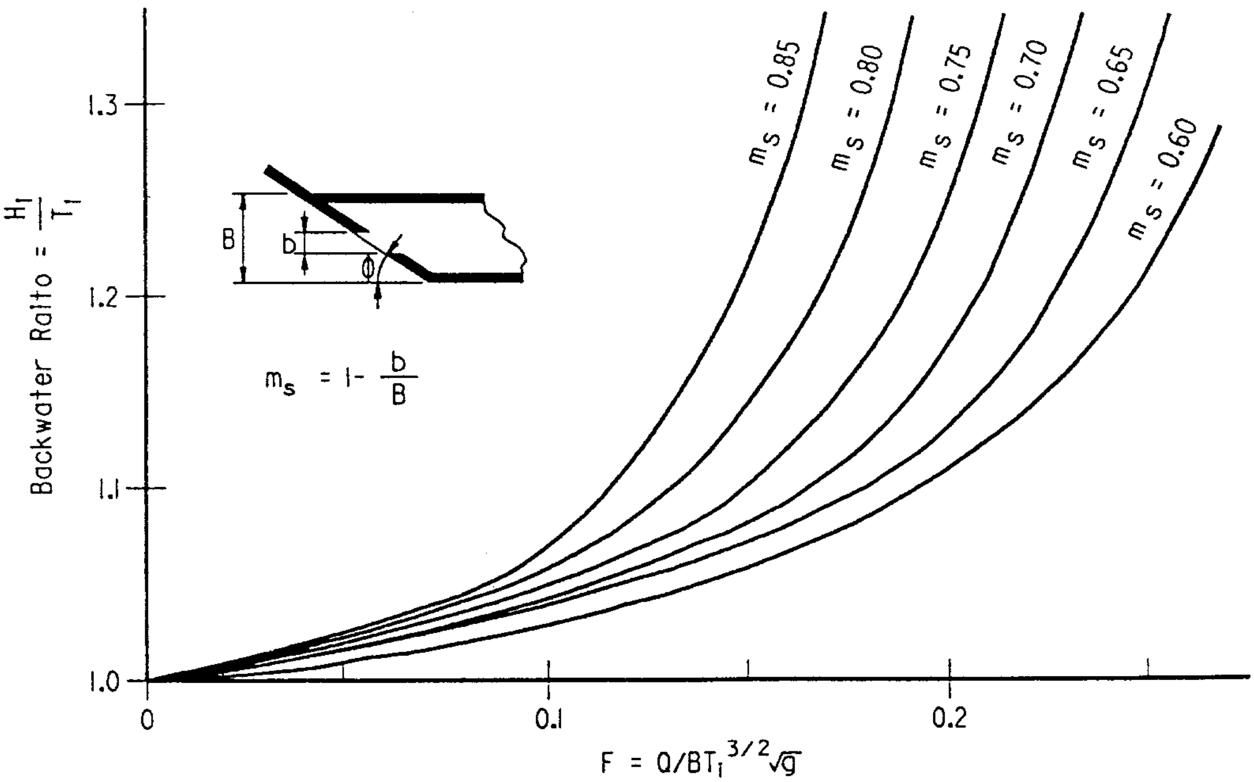


FIGURE 15-22 — Skewed Slot Rating Curve (ϕ = 30°)

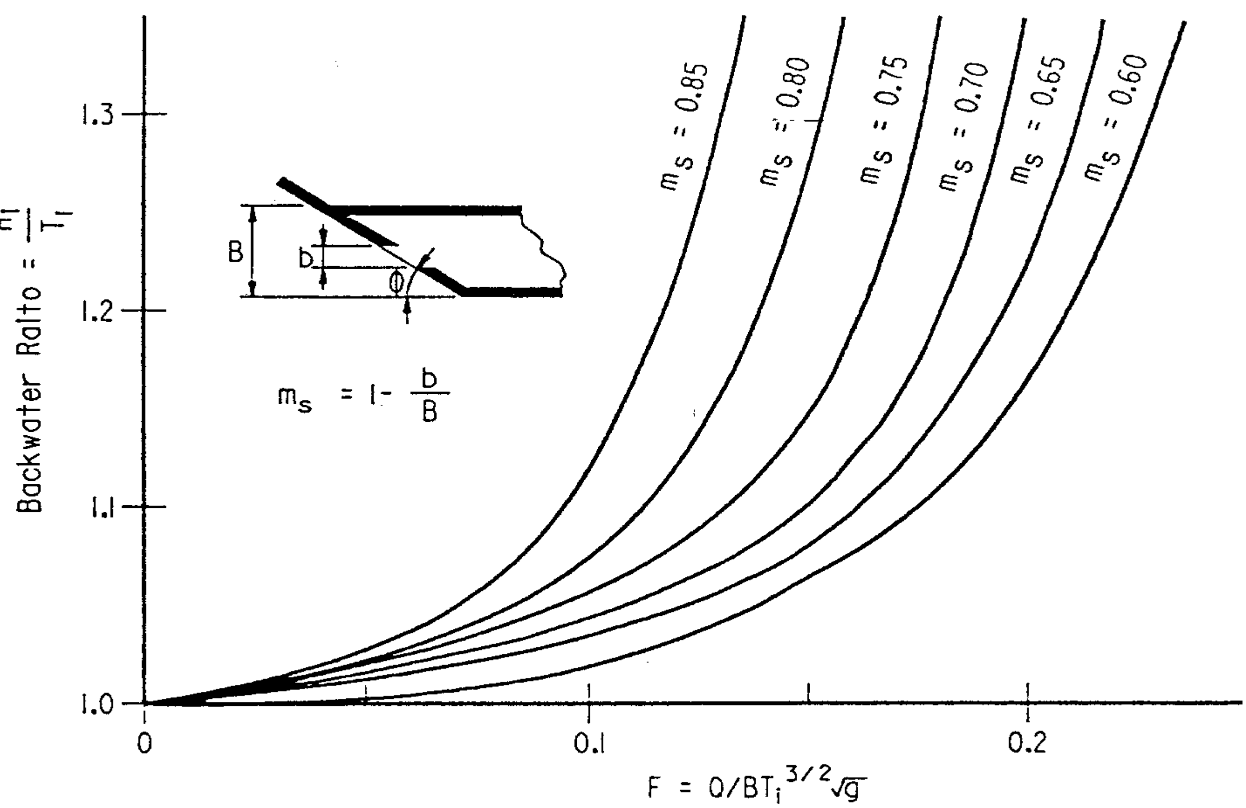


FIGURE 15-23 — Skewed Slot Orifice Rating Curve (ϕ = 45°)

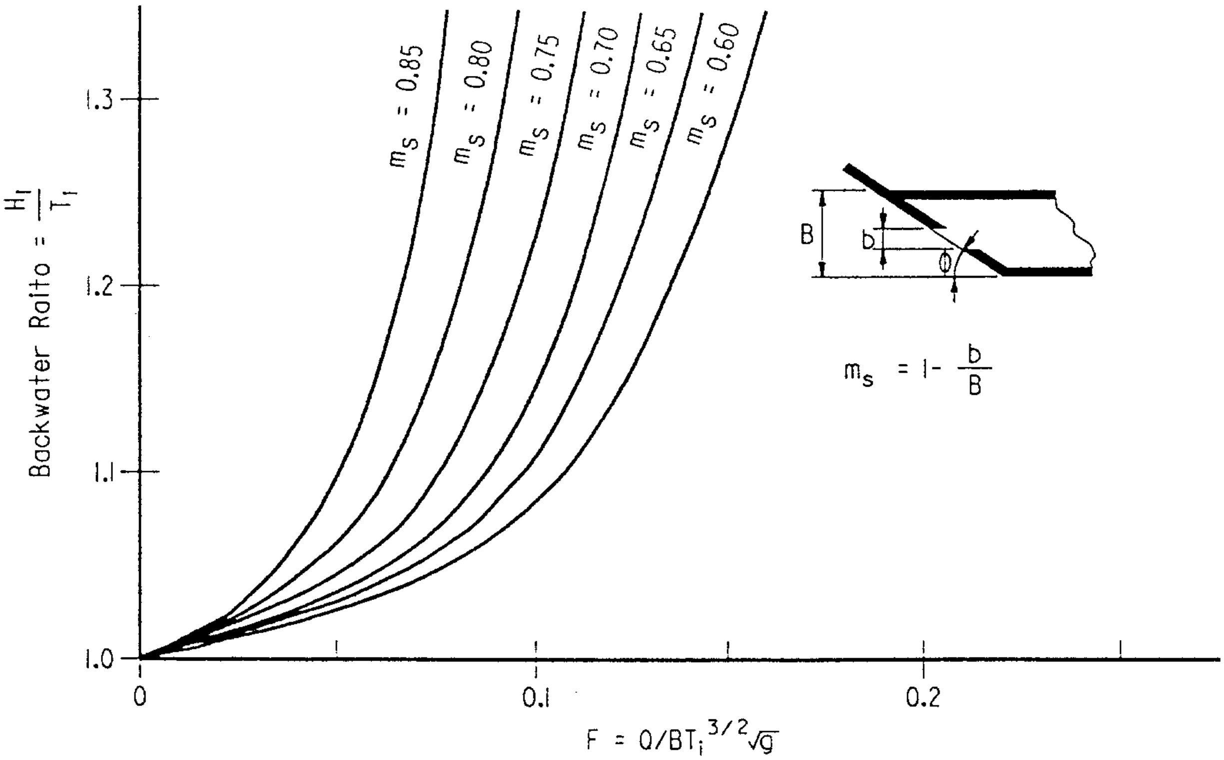


FIGURE 15-24 — Skewed Slot Orifice Rating Curve (ϕ = 60°)

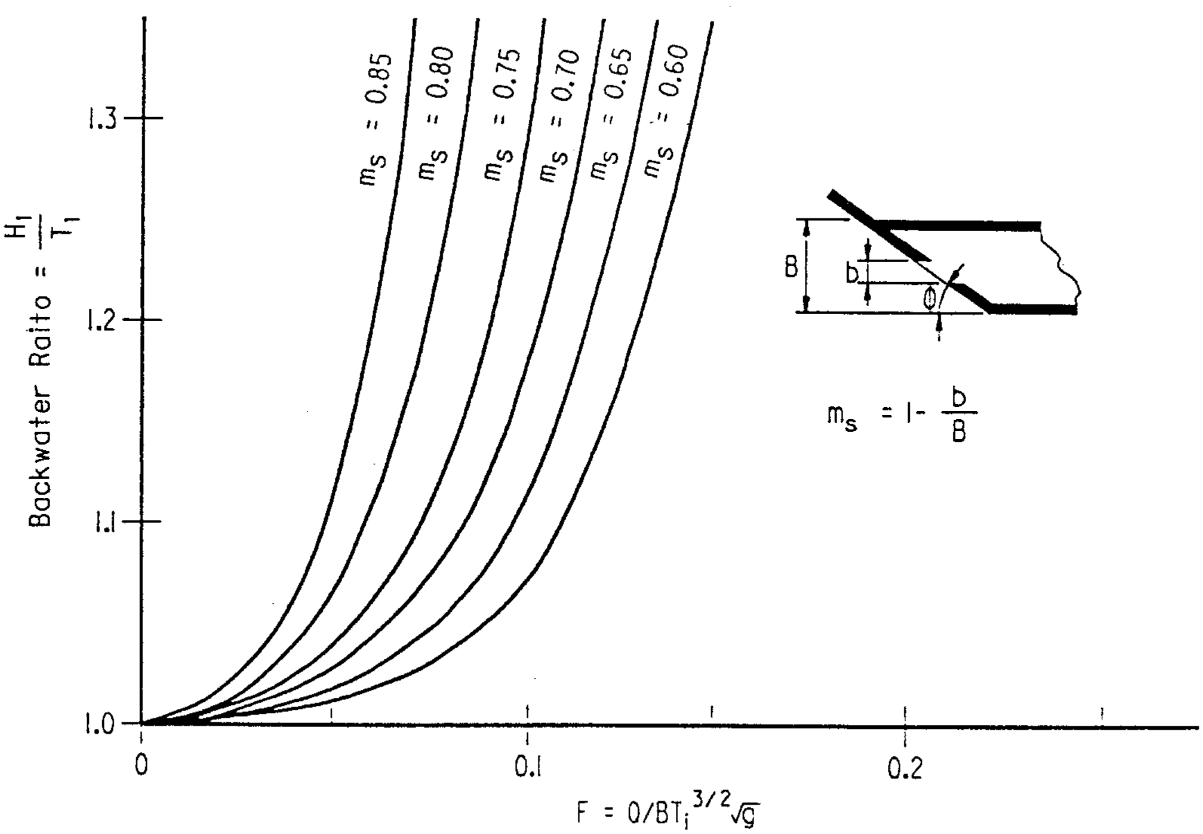


FIGURE 15-25 — Skewed Slot Orifice Rating Curve (ϕ = 75°)

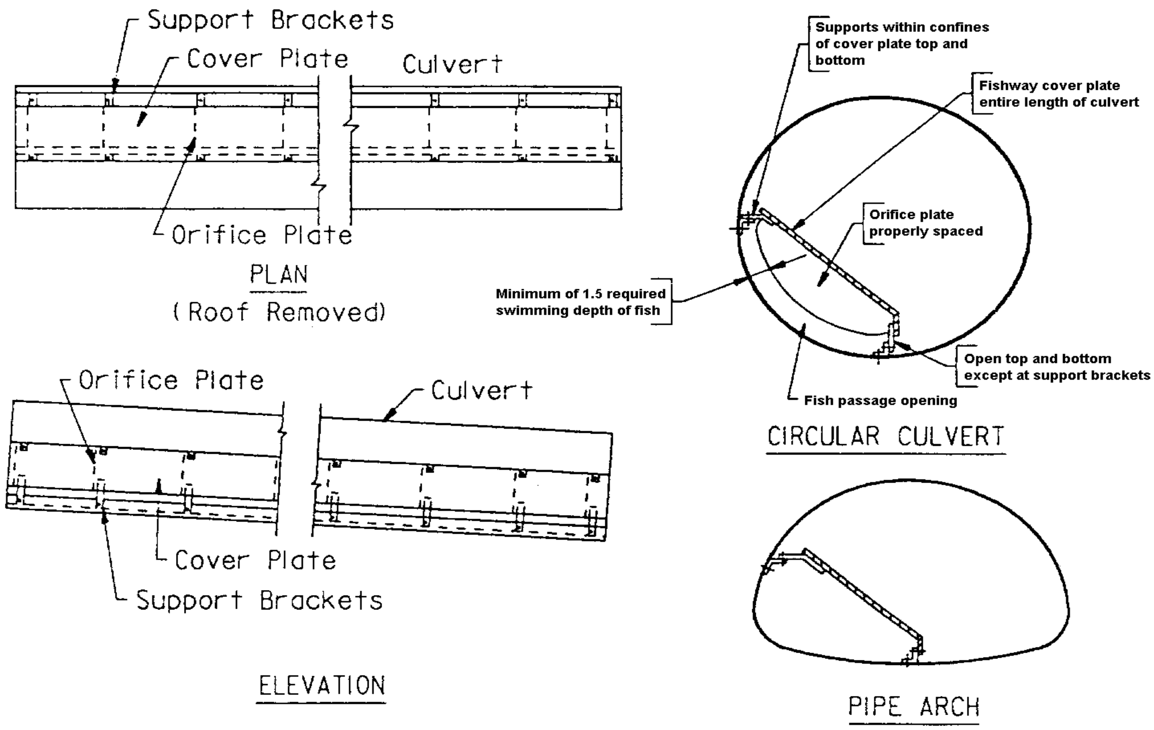


FIGURE 15-26 — Commercial Orifice Fishway for Culverts

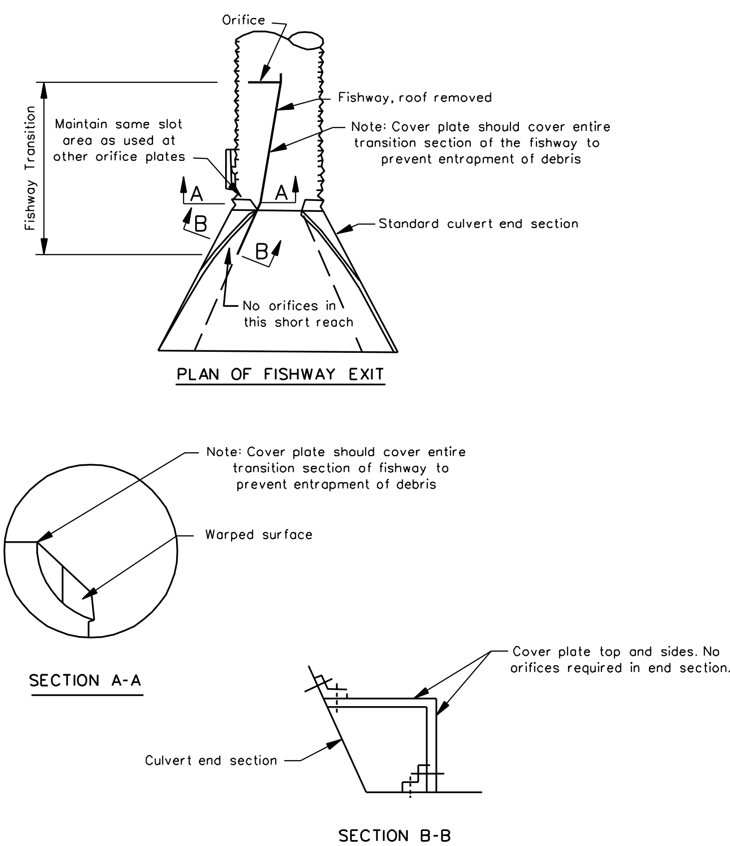


FIGURE 15-27 — Commercial Inlet for Fishway Exit

- nearly equal water pressures on either side of the fishway; and
- an ability for fish to move from the high-velocity culvert barrel area into the low-velocity flow in the fishway.

These units are installed in the barrel after the culvert is constructed. All support brackets and attachment hardware are within the confines of the fishway to minimize the opportunity for snagging debris. If an existing commercial culvert is obstructing fish movement, this type of fishway may be installed when low flows can be temporarily pumped or piped around the structure. With this type of fishway, the potential for trapping debris and floating ice must be considered. Structurally, this fishway must withstand the impingement forces caused by the expected debris. If even a portion of the fishway breaks free and jams within the culvert, the following could occur:

- culvert could be damaged,
- highway overtopping hazards may be increased, and
- upstream property could be unexpectedly inundated.

15.4.9 Sill/Baffle Hydraulics

15.4.9.1 General

Inherent in the outlet design (Section 15.4.7.3) and the following design procedures is the ability to estimate a depth-discharge relationship for sills or baffles (weirs) that are:

- broad crested,
- straight,
- notched, or
- a combination of these attributes.

It is also necessary to consider whether a sill or baffle is:

- submerged,
- partially submerged, or
- unsubmerged.

Sill and baffle hydraulics are estimated using the weir equation:

$$Q = CLH^n \tag{15.4}$$

where:
Q = discharge over the weir, ft^3/s
L = the weir length, ft
H = the total head on the weir, ft (includes approach velocity head and losses)
n = coefficient (1.5)

Where H is 1 to 2 times the weir thickness, T, as shown in Figure 15-28, the weir functions as a sharp-crested weir; otherwise, it is a broad-crested weir.

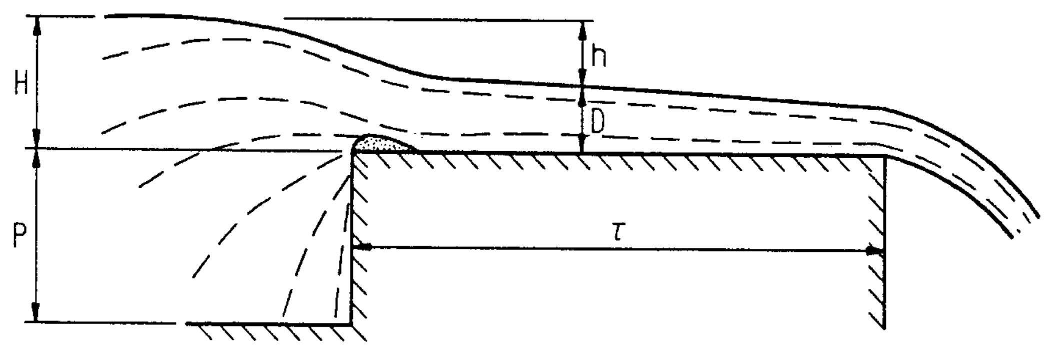


FIGURE 15-28 — Broad and Sharp Crested Weir

The coefficient C is a function of the average approach channel width, b, average crest length of the weir notch, L (for a sill that is not notched, use L = 0), the total head, H, the projection of the sill above the streambed, P, viscosity effects, K_L, and surface tension effects, K_H. The exponent, n, is 3/2. The relationship of these variables for weirs with end contractions is shown in Figure 15-29.

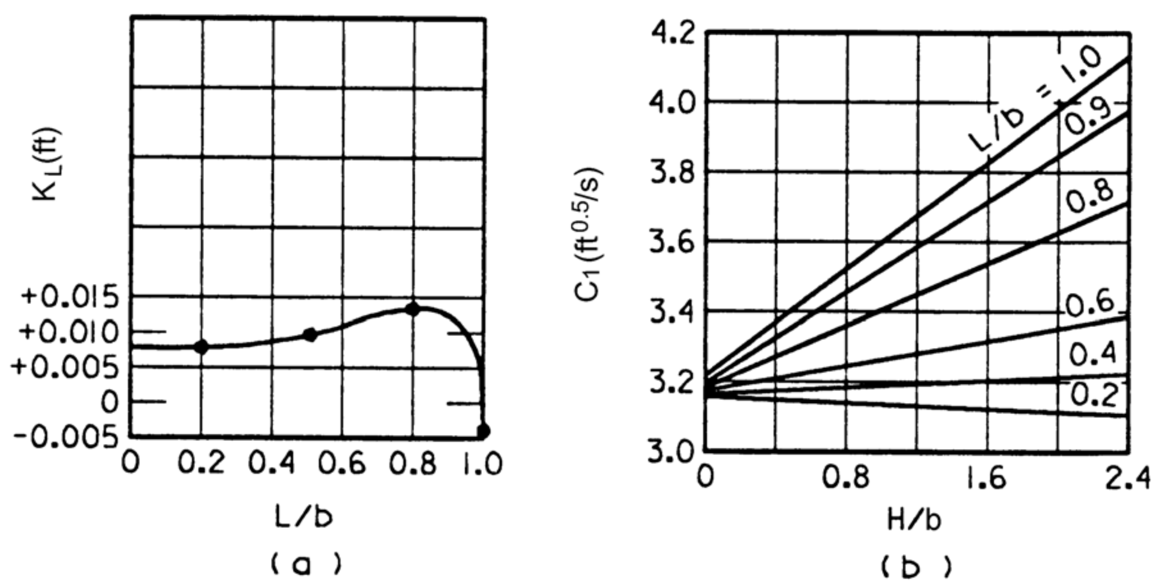


FIGURE 15-29 — Horizontal Sharp-Crested Weir Coefficients

15.4.9.2 Example

The following simple example illustrates a broad-crested weir analysis for a sill downstream of a culvert. Assume that the sill has rectangular notch. Select a sharp-crested weir equation for the first trial. The sill has a horizontal crest L = 3 ft long, is located P = 2 ft above the channel bottom, and is centered in a rectangular channel with b = 5 ft wide. The notch thickness, T, is 0.33 ft. Determine the discharge when the head, H, is 0.4 ft.

Assume for now that the weir is sharp-crested. Then:

$L/b = 3/5 = 0.6$
$H/P = 0.4/2 = 0.2$

From Figure 15-29:

$C_1 = 3.19$

From Figure 15-29, kL = + 0.012. For water, use $k_H = 0.003$; then the effective crest length, L_e, is:

$L_e = 3 + 0.012 = 3.012$ ft

and the effective head, H_e, is:

$H_e = 0.4 + 0.003 = 0.403$ ft

Then:

$Q_1 = C_1 L_e H_e^{3/2} = (3.19)\ (3.012)\ (0.403^{3/2})$
$Q_1 = 2.46\ ft^3/s$

Checking the foregoing assumption that this was a sharp-crested weir, compute:

$H_e/T = 0.403/0.33 = 1.2$

Because H_e/T is greater than one to two times the weir thickness, the initial assumption that this sill functions as a sharp-crested weir is acceptable.

15.4.9.3 Broad-Crested Weir

With a broad-crested weir, the exponent, n, is 3/2. The coefficient, C, varies from 2.63 to 3.087. Use 2.63 unless the upstream corner of the weir is rounded to where there is no contraction loss, and the weir crest, T, is sloped so that the slope equals the friction loss; with this geometry, the coefficient, C, is 3.087.

15.4.9.4 Vee-Notch Weirs

For sills having a vee notch, use Equation 15.5 to determine the notch hydraulics:

$$Q = 2.5 \tan(\Theta/2)\ H^{2.5} \tag{15.5}$$

where:
- Q = discharge over the weir, ft^3/s
- Θ = angle of vee notch, degrees
- H = the total head on the weir, ft (includes approach velocity head and losses)

Either the sharp-crested or broad-crested weir equation would be used for that portion of the remaining sill crest that is above the notch.

The coefficients for a vee-notch weir varies with the notch angle; see in Table 15-10.

TABLE 15-10 — Vee-Notch Weir Coefficients

Notch Angle (°)	C ($ft^{0.5}/s$)	n (-)
22.5	0.50	2.50
60	1.45	2.50
90	2.50	2.50
120	4.33	2.50

15.4.9.5 Submergence Effect

As the tailwater begins to submerge a weir, the discharge is reduced. Figure 15-30 reflects how the unsubmerged discharge, Q_1, is reduced as a function of head above the weir crest, H_1, and the depth to which the tailwater extends above the weir crest, H_2.

The following example illustrates the effect of some submergence on a vee-notch weir. Determine the discharge of a 90° vee-notch weir if H_1 is 0.9 ft, H_2 is 0.3 ft and $Q_1 = 2.5H_1^{2.5}$.

Using Curve 1 of Figure 15-30:

$Q_1 = (2.5)\ (0.9^{2.5}) = 1.92\ ft^3/s$
$H_2/H_1 = 0.3/0.9 = 0.333$
$Q/Q_1 = 0.972$ (from Curve 1)
$Q = (0.972)\ (1.92) = 1.87\ ft^3/s$

Using Curve 3 of Figure 15-30:

$(H_2/H_1)^n = (0.333)^{2.5} = 0.064$
$Q/Q_1 = 0.972$ (from Curve 3)
$Q = (0.972)\ (1.92) = 1.87\ ft^3/s$

15.4.10 Fish Passage Culvert Flood Hazards

The placing of substrate, boulders or sills/baffles inside of culverts may increase the existing flood hazards for both new construction and existing culverts. This placement is to be avoided unless allowances are made for such appurtenances. In addition to inundation, the primary engineering criteria to be used in fish passage design for minimizing potential increases in flood hazards are:

- drift and debris,
- sediment deposition, and
- ice.

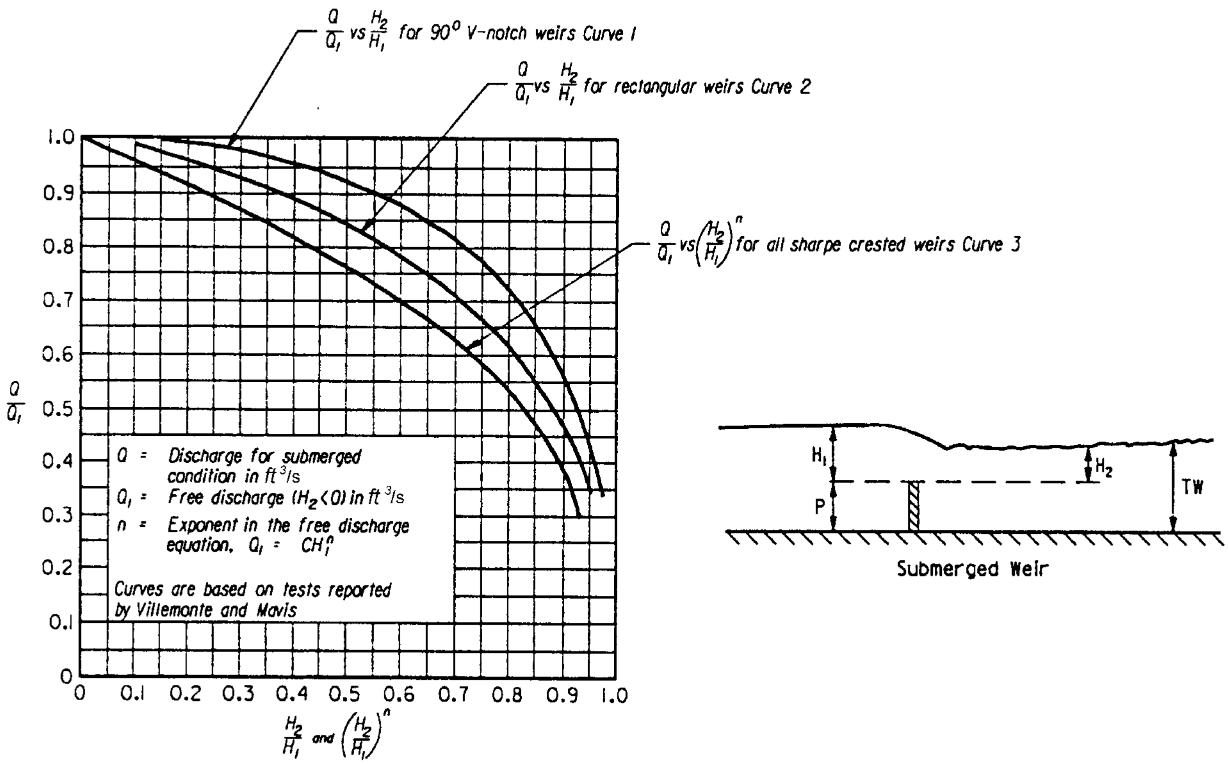


FIGURE 15-30 — Weir Submergence Effect on Discharge

15.4.10.1 Drift And Debris

Where drift and debris that might block a fish passage culvert is expected, consider:

- upstream debris traps,
- increasing the width and height (oversized culvert),
- grates on the fishway entrance,
- maintenance access,
- structural stability,
- a separate fishway facility, and
- flood easements.

15.4.10.2 Sediment Deposition

Where sediment deposition might adversely affect a fish passage culvert, consider:

- sediment ejectors located at the fishway entrance (see Figure 15-10),
- sloped sills (see Figure 15-7) or baffles,
- maintenance access, and

- a separate fishway facility.

15.4.10.3 Ice

Consider ice-related maintenance problems for:

- in-situ ice buildup, and
- ice flows.

IN-SITU ICE BUILDUP. Due to water from upwelling groundwater or melting from ice and snow entering a culvert where the colder ambient temperature causes it to freeze. Enough freeze and thaw cycles may cause a buildup of the ice inside the culvert to where the fishway and/or culvert capacity is inadequate. This buildup may also exert large forces that might damage the fishway.

ICE FLOWS. Culverts and fishways may be damaged by flood-borne ice. These same ice flows might also jam in, or near, a culvert due to the presence of sills or baffles. This may prevent fish migration, limit the passage of flood flows and/or cause fishway damage.

Where ice problems that might block or damage the fishway or the culvert are expected, consider:

- increasing the culvert width and/or height (oversized culvert),
- structural stability of the fishway to accommodate ice expansion and impact, and
- a separate fishway facility.

15.4.11 <u>Fish Passage Culvert Flood Hazards</u>

The placing of substrate, boulders or sills/baffles inside of culverts may increase the existing flood hazards for both new construction and existing culverts. This placement is to be avoided unless allowances are made for such appurtenances. In addition to inundation, the primary engineering criteria to be used in fish passage design for minimizing potential increases in flood hazards are:

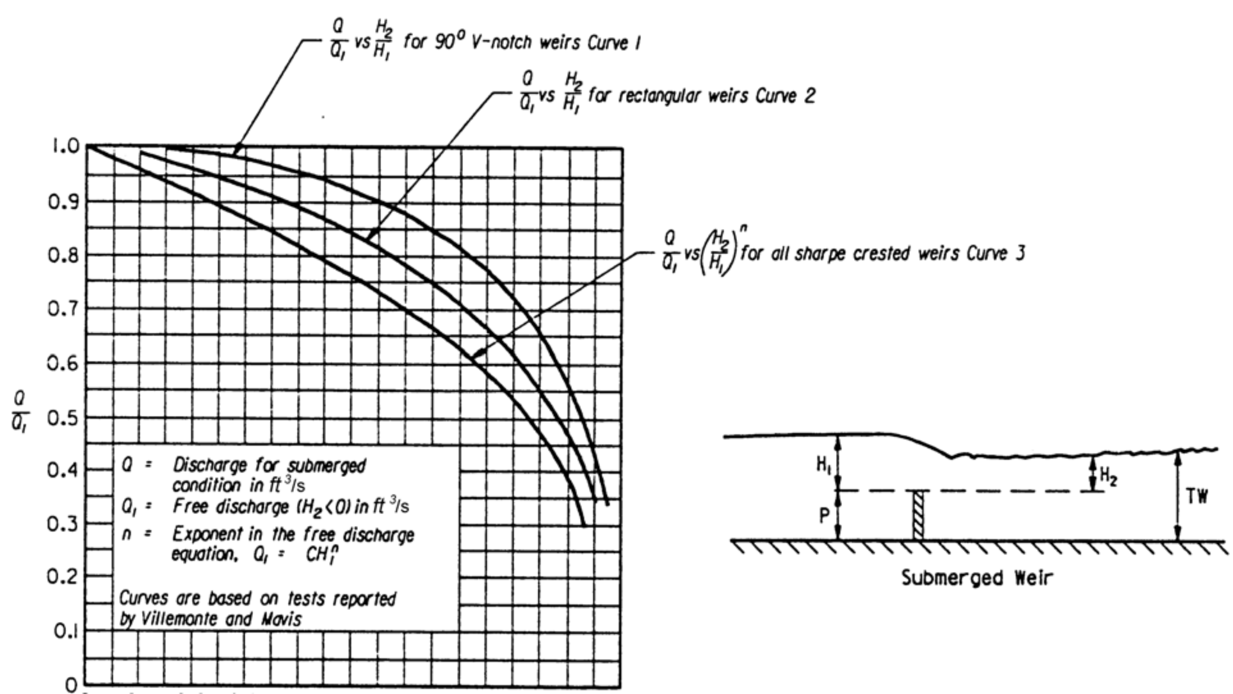


FIGURE 15-30 — Weir Submergence Effect on Discharge

- drift and debris,
- sediment deposition, and
- ice.

15.4.11.1 Drift And Debris

Where drift and debris that might block a fish passage culvert is expected, consider:

- upstream debris traps,
- increasing the width and height (oversized culvert),
- grates on the fishway entrance,
- maintenance access,
- structural stability,
- a separate fishway facility, and
- flood easements.

15.4.11.2 Sediment Deposition

Where sediment deposition might adversely affect a fish passage culvert, consider:

- sediment ejectors located at the fishway entrance (see Figure 15-10),
- sloped sills (see Figure 15-7) or baffles,
- maintenance access, and
- a separate fishway facility.

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Consider ice-related maintenance problems for:

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- ice flows.

IN-SITU ICE BUILDUP. Due to water from upwelling groundwater or melting from ice and snow entering a culvert where the colder ambient temperature causes it to freeze. Enough freeze and thaw cycles may cause a buildup of the ice inside the culvert to where the fishway and/or culvert capacity is inadequate. This buildup may also exert large forces that might damage the fishway.

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Where ice problems that might block or damage the fishway or the culvert are expected, consider:

- increasing the culvert width and/or height (oversized culvert),
- structural stability of the fishway to accommodate ice expansion and impact, and
- a separate fishway facility.

15.4.12 Maintenance of Fish Passage Culverts

Problems can occur when maintenance forces are unaware that some deposition in a countersunk culvert is essential. Also, maintenance forces should be made aware of the migration period(s) for fishways. Further, this allows maintenance forces an opportunity to ensure fishways are in good repair and clean prior to critical migration periods.

Caution is required when considering special devices where drift, debris, ice and high bed-load sediment transport rates occur. Where these stream-transported items may cause partial or total blockage of a culvert, smooth (not hydraulically smooth; see previous discussion) culverts with downstream sills, substrate culverts and bridges are preferred wherever practicable. Consider the higher maintenance costs when comparing alternative fish passage culvert types.

15.4.13 Stream Geometry and Cover

Channel disturbances are mitigated by employing those geometries necessary to restore and, where demonstratively appropriate and practicable, upgrade the functional values of a channel. Where mitigation is required, channels are designed and constructed to provide such functions as:

- riparian cover,
- instream cover,
- pools,
- riffles,
- water quality,
- substrate,
- bank geometry, and/or
- conveyance for the selected design flood.

With these types of channels, the selected design flood is that used to size the channel and any appurtenant culverts or bridges to avoid a flood hazard to the highway user and any property owners.

Practicable construction practices used to obtain the foregoing geometries and appurtenant features are shown in Appendix 15.B. This Appendix shows the Department’s preferred geometries used in mitigating channel disturbances. The use of these or other geometries must be negotiated with the responsible resource and regulatory agencies on a case basis. Aggressive revegetation and soil stabilization practices associated with these geometries are needed to restore and/or where mandated by the responsible resource and regulatory agencies, enhance a disturbed stream’s:

- riparian cover,
- floodplain vegetation, and

- other aquatic functional values.

Flood hazards must not be overlooked when designing an environmentally acceptable channel modification. To avoid flood hazards, appropriate channel roughness values are used in the hydraulic design of channels where instream habitat and/or riparian cover devices are employed. Based upon the selected instream and riparian geometries, select hydraulic channel design criteria and coefficients for such elements as:

- friction and bendway losses,
- sediment transport,
- stream stability,
- scour, and
- aggradation.

The design of a stable channel to serve the environmental needs set forth in this Chapter is addressed in the Channels Chapter. Essentially, the mitigation geometries of Appendix 15.B become appurtenant channel features in the stable channel analysis and are accounted for in the:

- Manning's n values selected for the channel analysis,
- hydraulic channel and structure analyses, and
- stability investigations.

15.5 DESIGN PROCEDURES

15.5.1 Design Steps

Environmental design procedures routinely involve some or all of three general steps:

- acquisition of the design data*,
- selection of the design fish*, and
- hydraulic analysis.

* *This may be accomplished in collaboration with the responsible resource and regulatory agencies.*

In this Section, design procedures are provided to illustrate the foregoing steps. Examples are in Appendix 15.C. Procedures are provided for:

- water quality control measures,
- environmental channels, and
- culvert fish passage.

Other procedures and examples may be included in this Chapter at a future date as they become available.

15.5.2 Design Data

Environmental design, at a minimum, requires two types of data:

- site-specific information, and
- surface water information.

Acceptable criteria for this design data should be negotiated with any responsible resource and regulatory agencies.

On rare occasions, the acquisition of some of the following data may require a controlled monitoring program. Such programs should have sufficient duration to provide unbiased data to identify any changes due to natural events and man-made activities such as:

- high runoff periods;
- annual climatic changes (seasons); and
- practices relating to agriculture, silvaculture and development.

15.5.2.1 Site-Specific Data

Hydraulic design data commonly obtained for each site as set forth in the other chapters of this *Manual* will usually suffice. Additional data may be required for the:

- design of water quality control measure(s), or
- complex fish passage analysis (see Section 15.5.4).

Water quality analysis addressed by this *Manual* focuses primarily on surface waters that may receive runoff from the highway right-of-way and thereby incur:

- permanent degradation,
- temporary degradation,
- preservation needs, and/or

Site-specific data other than that required in the other *Manual* chapters might be required for some or all of the following:

- erosion predicting variables for the soil such as allowable velocities, tractive shear and Manning's n values;

- hydrology and hydraulic variables associated with any selected vegetative measures such as daily hydrograph (24-h clock time vs. discharge), annual hydrograph, allowable construction slopes, flow velocities, tractive shear, vegetal growth characteristics and Manning's n values;

- vegetative area requirements to obtain acceptable rates of sedimentation and/or pollutant uptake;

- surface and subsurface soil and geology;

- surface and subsurface infiltration rates;

- rainfall-frequency-duration relationships;

- gradation curve for sediment subject to erosion, transport and deposition;

- topography, area and location proposed for any pollutant management measures;

- climate related erosion factors;
- source and amount of natural and/or man-made pollutants;
- hydrology and hydraulic characteristics of any pollutants such as solubility, adherence to sediments and settling velocities;
- seasonal groundwater elevations and water quantity;
- required multiple uses for basins; and
- other measures.

With fishery-related analyses, it may be desirable to have data to define the site's:

- annual (daily peak) hydrographs, and
- daily (24-h) hydrographs.

15.5.2.2 Surface Water Data

Water quality analyses for receiving surface waters may also require data for some or all of the following:

- pollutographs,
- hydraulic characteristics,
- hydrology,
- fish design, and
- other.

HYDRAULIC CHARACTERISTICS. The characteristics include such factors as relationships for:

- stage-discharge,
- stage-velocity, and
- stage-recurrence interval.

HYDROLOGY. Additional data may consist of such factors as the:

- annual (daily) hydrographs, and
- daily (hour) hydrographs.

FISHWAY DESIGN. It may be necessary to determine the design fish:

- run type(s);
- species that migrate and/or inhabit the stream;
- minimum swimming depths;
- swimming speeds;
- jumping or burst speeds;
- jump heights;
- migration delay durations;
- probable hourly run size;

- water volume requirements;
- vertical ascent time;
- instream, riparian and floodplain habitat needs;
- approximate date and times of migration; and
- fish size (fork length and total length).

Depending on the run type, this information may be needed for the entire fish population of the stream including both resident and migratory species.

15.5.2.3 Other

In addition to the foregoing data, the designer may need to negotiate design data for the following aquatic and floodplain-related investigations:

- material requirements for spawning bed restoration or preservation;

- variances for tolerable but temporary pollutant concentrations for the preconstruction, construction and post-construction periods – primarily for turbidity and sediment, but on rare occasions possibly other pollutants;

- instream and riparian habitat requirements for water fowl and other surface water inhabitants;

- habitat requirements for terrestrial (floodplain dwelling) wildlife;

- domestic animal requirements and their impact on surface waters*; and

- wetland requirements such as cover, water depths and pond geometries.

**Note:* *In many riparian localities, it is the domestic livestock that are the prime source of bank deterioration and other environmentally damaging actions.*

15.5.3 Water Quality Measures

Reference *(9)* is the principal source for these procedures.

Procedures for accomplishing mitigation using the following measures are provided:

- Standard BMP's,
- vegetative,
- detention basins,
- wetland, and
- infiltration.

15.5.3.1 Vegetative Measures

Vegetative design procedures should only be used in the wetter areas of the State, which can support vegetation having the necessary density. They should NOT be used in the arid and semi-arid regions of the State where the Standard BMP's found in the Departments Erosion

Control Manual are the preferred control measure to reduce the migration of pollutants off the highway right-of-way.

Vegetative design procedures fall into two general categories:

- vegetated channels, or
- overland (sheet) flow.

The essential design criteria are:

- provide sufficient vegetative cover to remove pollutants,
- ensure the stability of the selected vegetation, and
- provide for ongoing maintenance.

Considerations in selecting these design criteria are:

- topography,
- soils,
- area required,
- climate, and
- erosion potential.

15.5.3.1.1 Vegetative Channels

The design steps are summarized as follows. Because the design is a simplistic application of the allowable velocity and tractive shear practices in the Channels Chapter, an example is not provided:

Step 1 Estimate the expected runoff flow rates for a range of runoff events to include the 100-year review event; see Hydrology Chapter.

Step 2 Determine the most critical slope of a proposed channel or overland flow strip. Note, with tractive shear practices, there are two variables to consider — slope and flow depth.

Step 3 Review any environmental commitments.

- select appropriate vegetative cover,
- select an acceptable supplemental armor lining if needed,
- estimate the amount of pollutant removal which will be generated by the mature cover provided, and
- Identify workable alternative locations and configurations for the vegetative cover and any armor lining.

Step 4 From the Channels Chapter, select appropriate allowable values for:

- Manning’s n,
- critical velocity threshold, and
- critical tractive shear threshold.

Step 5 For the proposed steepest and flattest slope and a range of recurrence intervals, determine the expected channel and/or overland:

- flow depths,
- maximum (not average) velocity, and
- maximum (not average) tractive shear.

Step 6 Compare the expected range of hydraulic variables of Step 5 with the allowable variable of Step 4 for a range of recurrence intervals. If velocity or depth criteria are exceeded, upgrade the protection or modify the design. Repeat the foregoing Steps.

15.5.3.1.2 Overland (sheet) Flow

Erosion potential is most reliably evaluated by using Revised Universal Soil Loss Equation (RUSL). Any use of RUSLE should begin with Agriculture Handbook 703 (Renard et al., 1997), which provides the theoretical background and supporting materials for the RUSLE model, as well as providing extensive practical information describing RUSLE's use. This source is available at:

http://www.ott.wrcc.osmre.gov/library/hbmanual/rusle703.htm

15.5.3.2 Detention Basin Measure

This procedure is applicable for only wet detention basins. Dry detention basins are considered as being ineffective for pollution removal.

The following is an adaptation of the Driscoll method for estimating pollutant removal rates as recommended in Reference *(9)*. The method can be used to estimate either the:

- long-term efficiency of an existing wet basin, or
- dimensions of a proposed wet basin.

This method assumes that the design will ensure that the following design concepts will be met:

- permanent pool in the detention basin, and
- infiltration from the retained pool will increase mitigation performance under both dynamic and quiescent conditions.

The design Steps are summarized as follows:

Step 1 determine an acceptable location for a wet detention basin(s). For the proposed highway geometry, determine the hydrology for a range of recurrence intervals to include the base 100-year event; i.e., estimate the:

- flood-frequency relationship, and
- flood hydrographs.

Step 2 Determine the expected size distribution of sediment particulates and the distribution of pollutants in the runoff for a range of recurrence intervals from either:

- field discharge tests,
- field sampling, or
- computer simulations (see Subsection 15.4.3.2).

Step 3 Estimate the settling velocity versus time and depth relationship of the smallest expected particulates to be removed from either:

- laboratory tests,
- selection of the fall velocity, or
- a current hydraulic text.

Step 4 For the selected range of recurrence intervals:

- estimate the dynamic removal efficiency,
- estimate the quiescent performance, and
- plot the percentage of total suspended solids removed versus basin surface area.

Determine the dimensions of a proposed wet basin necessary to meet the following criteria:

- Achieve the desired removal rates for a selected recurrence interval negotiated UDOT Environmental Staff with any resource and regulatory agency(ies) using the foregoing plot as a guide.

- Minimize the potential for the inadvertent discharge of pollutants (sometimes termed "short circuiting").

- Have basin bank slopes of 1V:3H or flatter to maintain a good vegetative cover where practicable.

Step 5 (Optional) If the basin is to be used for flood peak attenuation in addition to mitigation, use the Storage Chapter to either:

- verify that the dimensions from Step 4 are adequate, or
- determine new dimensions.

New dimensions must be determined as being compatible with both flood peak attenuation and pollution control. This is done by repeating the foregoing steps.

15.5.3.3 Wetland Measure

The design of a wetland to provide acceptable levels of pollution control is presently beyond the scope of this *Manual*.

15.5.3.4 Infiltration Measure

The design of infiltration measures to provide acceptable levels of pollution control is presently beyond the scope of this *Manual*.

15.5.4 Fish Passage Analyses Type

There are two types of fish passage analyses:

- simple, and
- complex.

The simple analysis is preferred if it provides practicable findings. To simplify the analysis, it is necessarily conservative. The complex analysis is used when the simple analysis:

- findings are suspect,
- results in costly facilities, or
- findings are unacceptable to the responsible resource and regulatory agencies.

15.5.4.1 Simple Analysis

Design discharges are estimated using the Department's recommended flood-frequency relationship practices for the site as presented in the Hydrology Chapter. The hydraulic fish passage is then designed using the criteria and practices of this Chapter.

The peak discharge criteria to be used by the Department in the simple fish passage analysis is that corresponding to a 10-year recurrence interval unless mandated otherwise by the responsible resource and regulatory agencies. This results in a facility that will have at least a 90% chance each year of functioning as intended. The allowable culvert velocity criteria applicable during the related migration period are as follows:

- Culvert velocities should not exceed the adult fish sustained swimming speed for discharges corresponding to 40% of the 10-year peak.

- Depending on the run type and thus applicability, culvert velocities should not exceed the juvenile fish sustained swimming speed for discharges corresponding to 20% of the 10-year peak.

15.5.4.2 Complex Analysis

This analysis uses the annual and the 24-h hydrographs commonly available from stream gage records. The complex procedure requires that there be usable stream gage data available:

- at or near the site, and/or
- within the same hydrologic region.

Clearly, gage data at or near the site of interest is preferred. Such data are seldom available. When this occurs, a simple "synthesis" procedure should be considered. In this procedure, data from other applicable watersheds are non-dimensionalized so that they can be transferred to the site of interest. When transferring a non-dimensional, annual and maximum daily hydrographs to the site of interest, it is important that the runoff data be from watersheds that:

- are in the same hydrologic region as the site of interest,
- have similar watershed characteristics, and
- have response times compatible with the site of interest (date and time to the daily peak).

15.5.4.2.1 Non-Dimensionalizing

There are various ways of non-dimensionalizing the data found in stream gage records. In this *Manual*, non-dimensionalizing two runoff periods may be required. This would be where fish migration occurs during both periods. These two periods are termed:

- high-flow period, and
- low-flow period.

High-Flow Periods — The maximum daily discharges are divided by the annual maximum peak discharge to non-dimensionalize the annual hydrograph for the high-flow migration analyses.

Low-Flow Periods — The maximum daily discharges are divided by the maximum daily peak occurring during the low-flow period of interest to non-dimensionalize the annual hydrograph for low-flow migration analyses.

There are several ways of non-dimensionalizing the maximum daily (24-h) discharges. For the high-flow period, it is suggested that the daily maximum discharge be divided by the annual maximum peak discharge. With low-flows, the daily maximum discharge would be divided by the maximum daily peak discharge occurring during the low-flow migration period.

15.5.4.2.2 Minimum, Average and Maximum Daily Discharge

The question next arises as to which daily discharge to use. The records commonly provide the maximum daily discharge. However, if practicable and acceptable to the responsible resource and regulatory agencies, use the minimum daily discharge or, as a compromise, the average daily discharge, although this will result in a somewhat more conservative finding. Avoid using the maximum daily discharge commonly found in the records if possible because this will result in overly conservative and questionable findings.

As noted above, because many flow records reflect only the daily maximum peak discharge, determining the minimum and average daily discharge requires knowledge regarding the expected hourly runoff hydrograph for a 24-h period. Stream gage owners and/or operators can usually provide this information from their archives. This 24-h data for gage(s) at or near the site of interest (or within the same hydrologic region as qualified above) can be evaluated to determine an adjustment factor (always equal to or less than unity) for converting a known maximum daily discharge, as taken from the records, to the average or minimum daily discharge.

15.5.4.2.3 Computer Models For Data Transfer

Additional data that may be required are primarily that required for use with the more sophisticated computer models; special engineering and consultants familiar with these models may be required as well. These models and procedures are currently outside the scope of this *Manual*.

15.5.4.3 Procedures

The fish passage facility that is most appropriate for a particular site is determined through:

- analysis to determine functionability, and
- in collaboration with the responsible resource and regulatory agencies.

In general, the Department's preferred fish passage facility types in order of preference are listed below. Procedures are provided in this Chapter for these types:

- open bottomed,
- countersunk,
- smooth*,
- sills or baffles, and
- slot orifice.

**Not necessarily hydraulically smooth; see earlier discussion and next Subsection.*

Should it be determined that a particular type is hydraulically unacceptable, then:

- adjust the geometry,
- re-evaluate using the complex analyses,
- negotiate a change in the design fish criteria with the responsible resource and regulatory agencies, and/or
- consider another fishway type; see above.

Examples for these fishways for both simple and complex analyses are provided in Appendix 15.C.

15.5.4.4 Open Bottom

The simple procedure will be used to describe the analysis for an open bottom culvert. This procedure is illustrated with Example 5, Appendix 15.C. The procedural Steps are as follows:

Step 1 Using the criteria guidelines provided in this Chapter, negotiate with the responsible resource and regulatory agencies on the:

- type of migration run;
- species and size;
- minimum swimming depths;
- darting, burst and cruising swimming speeds for the adult design fish;

- darting, burst and cruising swimming speeds for the juvenile design fish if appropriate (see Fish Movement Type); and

- jumping abilities.

Step 2 Obtain the conventional site data for the hydraulic culvert design. Estimate the flood-frequency relationship to include the design and review flood for designing a culvert size compatible with the site's flood hazards (highway and adjacent property); include the 10-year flood because it is used to design the fish passage structure using the simple procedure.

Step 3 Design a culvert that will meet:

- highway needs, and
- flood hazard criteria in accordance with the Department policy.

Step 4 Examine the culvert's inlet, barrel and exit velocities to ensure that they will not preclude migration of the design fish based on the considerations found in Section 15.4. If these considerations cannot be met, then it is necessary to either:

- provide a downstream sill to reduce the velocities at the inlet, within the barrel and at the exit to acceptable levels;

- try another culvert size and/or type alternative; or

- select another culvert fish passage alternative.

Step 5 The selected design flood for the culvert must remain within the incised channel banks; i.e., no overbank flow occurs. This selected design flood is either the:

- design flood used to determine the open bottom culvert size to meet the Department's flood hazard criteria, or

- review flood at those sites where the Department deems foundation failure would be unacceptable.

Step 6 Select a structure size that essentially spans the incised channel.

Step 7 Evaluate the streambed stability to ensure that the culvert footings are secure from scour for the selected design flood.

15.5.4.5 Countersunk Culvert

The complex procedure may be used for the analysis of a multiple barrel culvert having one barrel countersunk (depressed below the expected streambed). The countersunk barrel should be filled with acceptable substrate material that resists displacement due to scour as discussed elsewhere in this Chapter. Single countersunk culvert facilities are typically oversized compared to non-countersunk facilities. Where more than one culvert barrel is required to convey the design flood, it is important that at least one barrel be countersunk to provide for fish migration during low-flow periods. Although not essential, in some instances, the economics may be more favorable where all barrels are the same size; this would be where all barrels must carry a big portion of the culverts' design flood. However, with commercially available culverts, it is not unusual for the countersunk culvert to be substantially smaller than the remaining flood passage barrels; i.e., the lower barrel is sufficient only for:

- fish passage, and/or
- conveyance of the dominant channel flow.

Usually the countersunk barrel is placed in the dominant (low-flow) channel with any remaining flood passage barrels having their inlet (and sometimes outlet) flowline elevations at a somewhat higher elevation — usually just below the floodplain elevation. The higher flood passage barrels are not countersunk.

This procedure is illustrated with Example 4, Appendix 15.C. The procedural steps are as follows:

Step 1 For the selected design fish, negotiate with the responsible resource and regulatory agencies on those items noted in Step 1 of the foregoing simple analysis procedure. In addition, also negotiate:

- dates of the expected migration, and
- reasonable migration delay times.

Step 2 (Optional) Using the 24-h gage data and the daily peak data found in the stream gage records for the design fish migration period(s), estimate a typical:

- daily (24-h) runoff hydrograph, and
- annual hydrograph.

Commonly, site-specific data can not be found. When this occurs, use non-dimensionalized data from streams in the same hydrologic area that are expected to have a similar runoff response. Adjust the findings from these records to the site in question based on the ratio of each drainage area raised to the corresponding power for that hydrologic region; then, dimensionalize the hydrographs.

Step 3 Estimate the channel hydraulics and stability for the reach in question for a range of discharges (see Channels Chapter). Where practicable, stabilize an unstable channel.

Step 4 From a stage versus main channel velocity curve, obtain an estimate of the maximum stage above which natural fish migration is not expected due to high-flow velocities and the design fish swimming speed. Similarly, identify those annual periods of low flow where fish migration would not be expected in the natural channel. This is done by plotting the minimum stage (flow depth) on the stage-discharge curve to obtain a corresponding minimum migration discharge. Plotting this minimum discharge on the annual, low-flow hydrograph for the migration period identifies those periods where the discharge is below the minimum migration discharge, and natural migration would not be expected due to shallow flow depths in the natural channel.

Step 5 Use the stage obtained from the stage-main channel velocity curve to obtain a discharge from the stage-discharge curve. This is the high-flow migration discharge, above which natural migration would not be expected.

Step 6 Transfer the migration discharge obtained from the stage-discharge curve to the annual high flow runoff hydrograph of Step 3. Identify the expected time periods and durations available for the fish to migrate through the reach in question during high flows.

Step 7 Devise a practicable, trial culvert geometry that essentially replicates the hydraulic characteristics of the main channel during critical movement Use a Manning's n value that represents the expected culvert bottom. At this point, it will be necessary to decide whether:

- the countersunk culvert is to be backfilled to perpetuate a substrate through the culvert; or

- lower barrel velocities and greater depths are to be obtained without backfilling (provided that it can be shown that the countersunk region will not be filled through bed load transport (see Culverts Chapter)).

With the second alternative, it will be necessary to show, at a minimum, that the tractive shear in the culvert will be greater than that in the natural channel for all discharges – particularly for the expected lowest discharge at which bed material transport can be expected.

Clearly, where there is only a single-barrel culvert, the flowline invert must correspond to that of the stream. With multiple barrels, the practice is not as simple. Place at least one barrel in the dominant (low-flow) channel. Any remaining barrels required for flows in excess of those approximately equal to the dominant discharge are raised above the streambed with an inlet flowline invert elevation corresponding, at a minimum, to slightly less than the dominant discharge stage. With the outlet invert elevation, one of two alternatives is used:

- *First Alternative* — Outlet invert elevation higher than streambed elevation for any raised barrels are such as to ensure submergence of the outlet as flood flows begin to escape the low-flow and/or dominant channel.

- *Second Alternative* — Outlet invert elevation of all barrels is at the streambed elevation.

With the first alternative, the purpose for outlet submergence at the point of incipient floodplain inundation is to minimize outlet erosion to the raised barrels due to headcutting of the dominant channel banks and adjacent floodplain; where this cannot be done (such as for land-use facilities), the necessary outlet protection will probably be unique and costly. With the second alternative, the intention is to use conventional outlet protection.

With the second alternative, some raised barrels may incur sediment deposition (usually at the outlet) should the total channel width required by all the barrels be greater than the dominant or low-flow channel width. This should not present a problem unless increased deposition occurs at the inlet as well.

Step 8 Where the lower culvert is countersunk and must have a substrate backfill, check the maximum tractive shear for the backfill material placed inside the culvert and compare it with the main channel's maximum allowable tractive shear for a range of discharges. Also, ensure that the culvert is large enough to facilitate placement of the substrate; this may actually govern the selected culvert size and thus become an economical detriment to this alternative.

Step 9 Compare the expected tractive shear for the substrate material placed in the countersunk culvert with the allowable tractive shear for the selected backfill material for the same discharge. Note that, if there is much temporary ponding, the discharge in the natural channel and that passing through the culvert will not correspond at the same point in time. When this occurs a culvert flood routing analysis will be required (see Culverts Chapter).

Should the actual tractive shear inside the culvert greatly exceed that expected in the natural channel for various stages, then the sediment rate out of the culvert is most likely to be much greater than the natural channel's transport rate into the culvert. If this occurs:

- select a larger culvert(s) to obtain slower velocities within the barrel,
- install sills or boulders to help retain the substrate material placed in the bottom of the countersunk culvert,
- use larger substrate material in the culvert, and/or
- re-evaluate the need to have a substrate in the culvert.

This Step is a rough check on whether the inflow sediment transport rate will approximate the outflow sediment transport rate of the culvert. However, if acceptable to the responsible resource and regulatory agencies, a scoured substrate within the culvert might be more desirable as velocities will be slower and the flow depths greater within the culvert.

Step 10 With countersunk culverts having boulders embedded in the backfilled substrate, use the pressure-momentum theory to ensure that the boulders will remain in place during large floods. Note that, with boulders, the culvert must also be large enough to facilitate their placement, which may again actually govern the selected culvert size.

Step 11 Using the range of flows expected to occur during the movement of the design fish, estimate the flow velocity and depth in the culvert. If these are unacceptable, select a different culvert size or fish passage alternative.

15.5.4.6 Smooth Culvert

The simple procedure will be used to illustrate an analysis for a smooth culvert. Again, in this context, a smooth culvert is any culvert meeting the following criteria:

- placed so that the invert flowline elevation corresponds to the expected streambed flowline elevations, and
- there are no special fishway devices within the culvert barrel.

This procedure is illustrated with Example 1, Appendix 15.C. The procedural steps are as follows:

Steps 1-4 Same as for an Open Bottom Culvert Analysis (Subsection 15.5.5.4).

Step 5 Design an outlet to ensure that the design fish can enter the culvert exit (see Section 15.4.7.3).

Step 6 The minimum flow depth through the culvert must equal or exceed that for the design fish. Recommended minimum flow depths for selected fish are shown in Table 15-8.

15.5.4.7 Sill or Baffle

The simple procedure will be used to describe the analysis for a conventional, rectangular culvert with sills:

Step 1 Same as for an Open Bottom Culvert (Subsection 15.5.5.4).

Step 2 Obtain site data and estimate the flood-frequency relationship. Needed will be the design and review floods for designing a culvert that is compatible with the site's flood hazards (highway and adjacent property). In collaboration with the responsible resource and regulatory agencies, obtain concurrence on:

- dates and discharge range during the expected fish migration,
- species and size of the design fish,
- swimming speeds for the adult fish, and
- swimming speeds for the juvenile fish if appropriate (see Fish Swimming Performance Characteristics; see Section 15.4.6.5).

Step 3 Select a trial sill spacing; see Figures 15-13 through 15-18.

Step 4 Design a culvert that is compatible with the site's flood hazards considering the increased roughness caused by the sills; see Figures 15-13 through 15-18.

Step 5 Determine the velocities over the sills and between the sills for the range of discharges occurring during fish migration. For low discharges, this may require use of a suitable weir equation to obtain the brink depth velocity for the trial sill; see Section 15.4.10. Additionally, a water surface profile may be required if the culvert is on a flat grade where the head (or tailwater) on a downstream sill (or outlet) totally or partially submerges the next upstream sill.

Unacceptable hydraulics for a straight-crested sill may reflect the need for a notched sill and/or different culvert width.

15.5.4.8 Slot Orifice

There are two design procedures for slot orifice fishways. These are where the culvert headwater and tailwater depths are either:

- nearly equal, or
- greatly unequal.

The procedural steps for designing a slot orifice fishway are as follows. This procedure is premised on the following assumptions:

- entrance, exit and all intermediate fishway orifices have identical geometry;
- pool surfaces are essentially horizontal between orifices; and
- discharges through all orifices is equal (steady flow).

This procedure is illustrated with Example 7, Appendix 15.C. The procedural steps are as follows:

Steps 1-3 Same as for an Open Bottom Culvert (Subsection 15.5.5.4).

Step 4 Determine the flow conditions in the channel; i.e., H_i and T_1 (see Figure 15-19).

Step 5 Select a trial fishway design geometry; i.e., values for B, m and an orifice spacing.

Step 6 Assume a trial discharge, Q, through the fishway. Suggestion: try a Q equal to the migration discharge(s) less that portion of the migration discharge expected to pass through the culvert outside the fishway.

Step 7 Using a trial Q and T_1, compute the value of the parameter $Q/(B_{Ti}^{3/2}g^{1/2})$. Enter Figure 15-18 to obtain the value* of H_i/T_i, and compute the value of H_1.

* *The value of the maximum H/T ratio should be T when limited to approximately 1.7. Depending upon the value of m, the discharge through a slot orifice is not a function of T when the H/T ratio exceeds approximately 2.0. Also, the turbulence created by the weir nappe falling into the lower pool is quite disruptive and is not conducive to optimum fish movement into the fishway. For these reasons, the H/T ratio for any slot should be limited to approximately 1.7.*

Step 8 Using this value of H_1, obtain the value of T_2; $T_2 = H_1 - S(\Delta L)$, where S = slope of channel and ΔL = longitudinal spacing of the slot orifice weirs.

Step 9 Using the value of T_2 and Q, compute the value of the parameter $Q/(BT_2^{3/2}g)$; enter Figure 15-18 and obtain the value of H_i/T_i. Compute the value of H_2.

Step 10 Repeat this procedure for each successive weir until H_i is obtained. Compare this computed value of H_i with the known value of H_i for flow conditions in the upstream channel as determined in Step 4.

Step 11 If H_i computed does not equal the known H_i, assume a new value of Q and repeat the foregoing computations. If H_i computed is larger than the known H_i, the assumed value of Q was too large. If H_i computed is smaller than the known H_i, the assumed value of Q was too small. The Q through the fishway and the remainder of the culvert should not differ greatly from the selected migration discharge(s).

15.6 REFERENCES

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